ECONOMIC BOTANY

Devoted to Applied Botany and Plant Utilization

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Technical Literature Review

Utilization Abstracts

By the editor

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Why Another Botanical Magazine?

To serve as a common meeting place for botanists, interested primarily in fundamental principles, and others who are concerned with economic applications of those principles and with the industrial utilization of plants and plant products.

WILLIAM J. ROBBINS
Director, The New York Botanical Garden

MAN has always been dependent upon plants for his food, the oxygen he breathes, for fuel, for clothing, for much of his shelter, for various medicines and for innumerable comforts and conveniences. Without plants there would be no animal kingdom, and man himself could not exist. This basic economic importance of plants is recognized in the name used for the scientific study of plants—Botany—which is derived from a Greek word meaning to eat, and the early history of botanical science shows clearly its origin in the use of plants for food and for medicine.

From plants we obtain linseed oil, corn and coconut oil, turpentine, lacquer, varnishes and resins, coffee, tea and other beverages, perfumes, flavorings and spices, drugs and insecticides, paper, cordage, cellulose for artificial silks and a hundred other useful products. How much of our economy depends upon many of these plant products, some from distant places, was emphasized by our experience during the past war which cut us off from normal supplies. Rubber and quinine are two of the products, the shortage of which was felt most keenly, but there were many others, for example, the sponge of the luffa gourd, the insecticide pyrethrum, chicle for chewing gum, the drug ergot, agar agar and cork. On the detrimental side, bacteria, yeasts and molds cause disease in other plants and in animals and man, rot wood and cloth, mold food, short-circuit electrical instruments and deteriorate optical equipment in the tropics.

Another way in which plants contribute to our economic system is through the association of microorganisms in the formation of various products, for example, cheese, the production of which depends upon the activity of the lactic acid and other bacteria and various molds; beer, wine and other liquids fermented by yeast; sauerkraut, vinegar, soy sauce and many others less well known or desirable. Bacteria, yeasts and molds, as we learn to know them better, are increasingly used for producing specific chemical compounds which are beyond the skill of the laboratory worker or which can be made more cheaply by the microorganism. Alcohol, acetic acid, acetone, glycerine, citric acid, gluconic acid and riboflavin are some of these compounds. The most recent and illustrious additions to this list are penicillin and streptomycin.

In spite of the essential importance of plants for our existence, periodical magazines devoted exclusively, at least by title, to the economic values of the plant kingdom are few in number. The journal *Angewandte Botanik—Zeitschrift für Erforschung der Nutzpflanzen* was initiated in 1919, *La Revue de Botanique Appliquée et d'Agriculture Tropicale* begun in 1901 and the *Revue des Cultures Coloniales* founded in 1897. Other

journals of more general scope include articles on economic botany, for example, *The Chemurgic Digest* and *The Journal of Agricultural Research*. Still others, as those concerned with plant diseases and various aspects of horticulture, deal to a considerable degree with specialized fields of applied botany. However, unless others have escaped my attention, periodicals which endeavor to cover the field of plant utilization in a more or less all embracing manner are few indeed.

In an effort to remedy this paucity of periodical information on an academic level in America, there now appears ECONOMIC BOTANY, of which this issue is the first number. The particular name selected for this journal is of relatively minor importance, for it might as well have been titled by some other term to indicate that it is concerned with furthering the application of the knowledge of plants in general to human affairs.

It is not necessary to elaborate further on the importance of plants to man and on their number and variety, nor to emphasize that the potentialities of the plant kingdom still to be developed are limited largely by our knowledge of it and our desire and ability to use that knowledge. It must be realized, however, that knowledge is one thing and its application to human problems another. The individual or group with the requisite knowledge may be unfamiliar with or uninterested in practical problems, and, on the contrary, the man confronted by a problem may be unacquainted with the knowledge he requires to solve it.

A journal of applied botany is therefore needed to bridge the gap which always exists between knowledge and its application, between those interested in knowledge for its own sake and those interested in it because of its usefulness. This can be accomplished, in part, by publishing information on plants of potential economic importance, on the less well known methods and facilities by which plants and plant products are used, on problems encountered in utilizing botanical materials, on botanical principles which may be of practical significance, and on many other subjects which space here does not permit to be enumerated.

Of course, it is not possible nor desirable to separate sharply botany from economic botany. This is generally true of so-called pure and applied science. The investigator of a problem of importance to industry may discover principles of general application and thus add to the total of knowledge in that field; the scientist driven only by his own curiosity or his dissatisfaction with answers to questions which have no immediate application may uncover information which becomes the basis of a new industry or makes an old one more effective. Pasteur, for instance, did not hesitate to investigate the spoilage of beer, diseases of silk worms or anthrax of cattle and sheep, problems of practical importance. Yet his discoveries gave us fundamental concepts which opened an entire segment of biological science. Furthermore, an investigation of the genetics of the fruit fly or of the pink bread mold establishes principles which may be applied to the breeding of wheat and cattle.

To develop a journal which will serve, in a sense, as a common meeting place for botanists, interested primarily in fundamental principles, and those concerned with their application and development is highly desirable in today's ever increasing state of technological specialization. It is the purpose of ECONOMIC BOTANY to meet this need, as well as to provide information for those who value knowledge purely for the sake of learning.

Hybrid Corn—*Science in Practice*

In the production of which, the application of genetical knowledge and technique has increased the American corn crop billions of bushels, worth billions of dollars.

GORDON MORRISON*
Burgess Seed and Plant Company, Galesburg, Michigan

THANKS to hybrid seed, many more bushels of corn of better quality are now produced nation-wide on fewer acres than formerly and at much less cost per bushel in terms of man power. This gratifying state of affairs derives from a discovery made more than forty years ago by Dr. George Harrison Shull. Shull was then engaged in research in pure science at the newly established Station for Experimental Evolution of the Carnegie Institution of Washington at Cold Spring Harbor, Long Island, New York.

Following the rediscovery of Mendel's Laws Shull set out to discover the basic principles of the origin and inheritance of new characters. His primary purpose in studying corn was to determine the effect of inbreeding upon the inheritance of numbers of rows of grains on the ears. In the course of his experiments Shull isolated numerous highly inbred lines of corn. Manifestations of hybrid vigor in the progenies from controlled crosses between highly inbred lines impressed this farm-bred researcher that he was dealing with a principle of tremendous practical importance. Shull realized that he had within his grasp an improved method of corn breeding; a means of realizing higher yields of corn through utilizing hybrid vigor.

Shull called his new corn-breeding technique "A Pure Line Method in Corn Breeding". However, the end product of this new method of corn breeding—namely, seeds for farmers' use—has become known throughout agricultural science and industry as "Hybrid Corn" or as "Crossed Corn", since the seed crop is indeed hybridized-corn or crossed-corn.

What is a Hybrid?

Some readers may feel that undue liberties have been taken by corn breeders in such use of the term "hybrid". The term was used by earlier biologists and laymen to designate the offspring from a cross between members of different species. Thus the mule is a hybrid of the horse and jackass.

Modern plant breeders use the word "hybrid" to designate all cases in which the parents differ in one or more hereditary traits. Thus when we cross varieties of garden bean that differ in color of pods we may say that the first generation offspring are hybrid for wax and green pod color.

Hybrid Corn is a Special Kind of Hybrid

In Hybrid Corn the term "hybrid" is used in a very special sense. It desig-

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nates corn seed which is the result of *completely controlled* crossing of chosen uniform inbred strains. Good hybrids that find use in agriculture are derived by crossing and testing large numbers of inbreds. This serves to disclose those combinations of inbreds which impart to their hybrid offspring unusual vigor and capacity for relatively high yields of grain and fodder. Adapted hybrids commonly produce yields 10% to 30% greater than the corresponding open-pollinated varieties under similar circumstances.

There are several kinds of corn hybrids in use in practical agriculture, including single crosses and double crosses. Hybrid Corn seed of commerce is not made hybrid by controlled hand crossing but by a dependable field method outlined in the section devoted to the technique of mass production of Hybrid Corn.

For a technical discussion of the little understood but very valuable phenomenon of hybrid vigor the reader is advised to consult "Hybrid Vigor and Corn Breeding" by F. D. Richey, which appeared in the September, 1946, issue of the Journal of the American Society of Agronomy.

History of the Origin of Hybrid Corn

Shull's first major experiment at the Station for Experimental Evolution was devised in 1904 to determine what influence the method of breeding has on the production of mutations and on their frequency of occurrence. For this purpose Shull obtained a foundation stock of Evening Primrose collected in the wild by Hugo de Vries.

De Vries had differentiated sharply two kinds of variation, namely, mutation and fluctuation. It seemed desirable to Shull, in connection with his experiments on the effects of cross and self fertilization on mutations, to study also the relative influence of cross fertilization and self fertilization on the extent of fluctuating variation in a cultivated plant such as corn. Shull chose as an ideal object for such an investigation the numbers of rows of grain on the ears of corn.

Since Shull had started his research with previously unstudied Evening Primrose it seemed desirable to start the

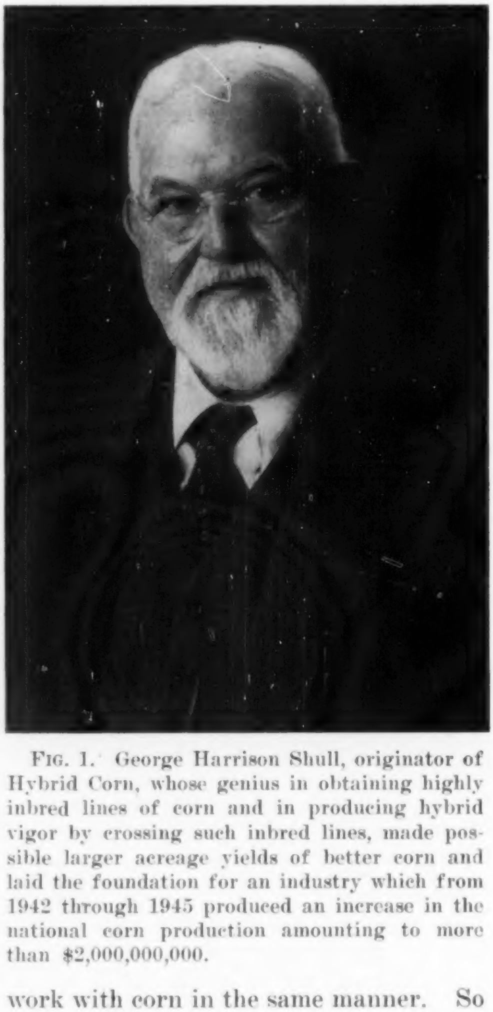


FIG. 1. George Harrison Shull, originator of Hybrid Corn, whose genius in obtaining highly inbred lines of corn and in producing hybrid vigor by crossing such inbred lines, made possible larger acreage yields of better corn and laid the foundation for an industry which from 1942 through 1945 produced an increase in the national corn production amounting to more than $2,000,000,000.

work with corn in the same manner. So he proceeded to count the rows of grains on the ears of several bushels of corn that the station had bought as horse feed. He saved ears for planting which belonged to each row class, from the lowest to the highest row number. There

was no preconception on the part of Shull that he was destined in this experiment to lay the foundation for a major improvement in farm technique that would make possible the production of more corn on fewer acres and with less labor. That does not mean, however, that Shull did not realize the importance of such improvement in agricultural techniques. If he had been actually aiming at such improvements, he probably would have given up the experiment when he found that each successive generation of inbreeding resulted in deterioration in yield as compared with the preceding generation. Since Shull was not interested at the time in an *increased yield*, but only in the question "What will happen?", he was intrigued tremendously in noting the fact that each successive generation of controlled self pollination in corn produced *less* deterioration than the one preceding. This led Shull at once to the view that a limit would be reached at which further deterioration would not result from continued inbreeding. Already by 1907 the segregation of strikingly unlike lines made the conclusion inevitable to Shull that he was deriving many distinct biotypes from what seemed like merely a fluctuating series of variations in a population. During the summer of 1907 Shull explained the situation in detail to various visitors including Dr. Edward Murray East.

Incidentally, it needs to be said here, in the interest of historical accuracy, that East's name has often been linked in misleading manner with Shull's in relation to the origin of hybrid corn. Much of the literature, particularly genetic text books and popular books on plant improvement, have implied or stated specifically that Shull and East arrived at the same conclusions about hybrid corn simultaneously and quite independently of each other. As a matter of fact, Shull and East began working with self-fertilized lines of corn at about the same time, namely about 1905, but at different experiment stations and entirely independently. Shull based his proposals for Hybrid Corn solely upon his own experiments. These proposals remain today the basis of the development of Hybrid Corn seed as it is produced for nationwide use on more than half of the national corn acreage. On the other hand, East minimized the importance of Shull's proposals by stressing the fact that the experiments had been conducted on a small scale and that the conclusions, although probably scientifically correct, were of no practical value. Indeed, East, as late as 1912, recommended crossing of varieties as the most practical means of utilizing hybrid vigor, thus leaving Shull's proposal the only one which advocated seriously the utilization of inbreeding as a preliminary phase of the production of hybridized seed corn.

In announcing his early experiments that served to inaugurate a new era in corn breeding, Shull prepared in 1907 his first paper on corn breeding for the American Breeder's Association. This paper, entitled "The Composition of a Field of Maize", was read at the annual meeting in late January, 1908, in Washington, D. C., and was published later the same year in the Proceedings of the American Breeders' Association.

The next year, 1909, Shull read his epochal paper, "A Pure Line Method in Corn Breeding", before the American Breeders' Association, assembled in Columbia, Missouri. This paper was published in the yearbook of the American Breeders' Association, Volume 5.

In the course of his studies on the origin and inheritance of new characters, Shull discovered that by inbreeding to isolate pure breeding types he was indeed determining by genetic analysis the hereditary composition of a field of corn.

In the American Breeders' Association article of 1908 Shull reasoned that the

difficulties, such as lessened size and vigor, that had often been encountered in attempting to improve open-pollinated crops by inbreeding, could hardly be explained by the harmful effects produced by the accumulation of disadvantageous individual variations. Many crops, including peas and beans, wheat and barley, have been naturally and exclusively or almost exclusively self-pollinated for countless generations with no apparent ill effects. Shull deduced that continued self-fertilization simply isolates, in due time, various pure-breeding "biotypes" or strains by separating them from hybrid combinations. Thus the differences between inbreds is due to the different hereditary factors possessed by the various inbreds.

Shull concluded in 1908 that the fundamental problem in corn breeding is the development and maintenance of that hybrid combination which possesses the greatest vigor, since the most important characteristics for which the corn breeder strives are those closely related to the question of physiological vigor.

Impressed by the yields of inbreds compared with the greater yields and the remarkable uniformity of some first generation hybrids, Shull reasoned that separating and recombining of definite pure lines might yield valuable results.

Shull's Directions for Obtaining and Utilizing Hybrid Vigor in Corn

Based upon his own investigations and demonstrations, Shull suggested in 1908 the following procedure for the corn breeder interested in obtaining results of practical value:

(*a*) Obtain by controlled self-pollination as many self-fertilized ears as practicable of the variety he is attempting to improve.

(*b*) Continue selective inbreeding until strictly uniform lines have been established.

(*c*) Make all possible combinations of crosses between these inbred lines.

(*d*) Grow all first generation hybrid combinations in comparative tests and study them carefully as to relative yield and the possession of other desirable qualities.

(*e*) Maintain isolated plots for the continuance of those inbreds which provide the best combinations.

(*f*) Maintain an isolated plot for the production of crossed corn for growers' use as seed corn by growing inbreds in alternate rows and detasseling early the rows of the female parent which is to yield the crossed corn for growers' use.

Shull did not himself use the detasseling method he recommended to the practical corn breeders. All pollinations in both selfing and crossing were carried out with meticulous care by hand pollination.

It is significant that Shull's paper on his new method in corn breeding and his demonstration received scant acclaim from his corn belt audience. Had his listeners seen through the rather clear though necessarily academic demonstration, they could have advanced practical corn growing at once. They could have avoided a lag of fully a quarter-century in the ultimate utilization of hybrid vigor in corn growing. It is true that Shull used in his studies and in his demonstrations ordinary field corn from the eastern seaboard. Shull's relatively vigorous hybrids were far superior to their inbred parents and were equal to the best specimens in the ordinary field from which the initial selections had been made. Nevertheless, the audience included conservative, skeptical corn growers who saw Shull's vigorous hybrids as scrubby things indeed compared with the tall, large-eared corn-belt varieties. The apparent failure to foresee that the same percentage gains might be realized with local varieties as Shull demonstrated with eastern types held progress in check.

One important difficulty was encountered in carrying out Shull's program in

practice. Many valuable inbreds are by nature very low yielding, and thereby, when crossed to produce hybrid seed, the yield of first generation hybrid seed for farmers use is so low that seed production is unprofitable. This difficulty was overcome by Dr. D. F. Jones, the brilliant geneticist who has specialized in corn breeding at the Connecticut Agricultural Experiment Station for many years. Jones retained Shull's pure-line idea intact and went a single logical step forward by proposing that two first generation hybrids—each derived from a pair of inbreds—be utilized by crossing them again similarly. Thus hybridized seed corn needed by the farmer could be produced upon the highly productive first generation hybrid instead of upon the relatively unproductive inbred used as the female parent in the first field crossing plot. Jones's proposal of the "double cross" or "4-way cross" reduced greatly the cost of seed production and has long proved of tremendous practical importance.

When Jones first arrived at New Haven he was quite surprised to see that Hybrid Corn was not being used. Jones got together all of the available inbreds and put them in a small crossing plot on the Mt. Carmel farm in 1916. A few inbreds yielded 20–30 bushels per acre of seed but most of them were very low. The combination that gave the best single cross hybrid yielded only about two bushels of seed. Jones saw that this was prohibitively expensive, and the seed was so poor in quality that farmers would not plant it. Having on hand single crosses of distinct type it seemed worthwhile to cross these again. Accordingly a small crossing plot was grown in 1917 with the best Leaming single cross as pollinator and several other single crosses as seed parents. When tested in 1918 the combination of Burr White (020 × 022) × Leaming (0243 × 0242) gave outstanding results. This was tested several years in trials at the station farm and in farmers' fields.

Hybrid Corn seed was first produced for commercial use by George S. Carter, Clinton, Connecticut, in 1921. The amount of seed was not large at any time but was widely distributed until the western hybrids came into production about 1930. These proved to be so

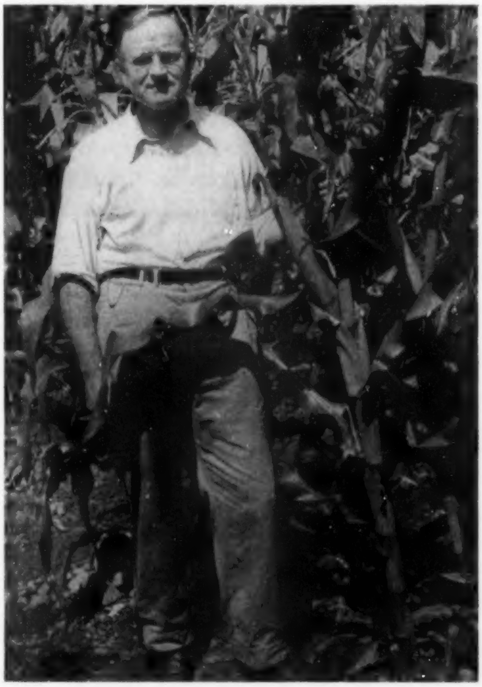


FIG. 2. Donald F. Jones, geneticist and resourceful field technician, whose device of the double cross, *i.e.*, the field crossing of first generation hybrids, overcame the objection of low yields of hybridized seed and made possible the profitable practical use of Shull's method of Hybrid-Corn seed-production for widespread use by corn farmers.

satisfactory and were produced so much more cheaply in the west that soon most of the hybrid field corn grown in the east was of western origin.

However, in February, 1945, research workers interested primarily in the northeastern States met at New Haven, Connecticut, to consider problems of corn improvement primarily concerned

with genetics and to develop a coordinated program of corn research in the northeastern area that will promote the production of corn hybrids with as wide usefulness as possible.

Henry A. Wallace and Hybrid Corn

The name of Henry A. Wallace is prominent in the history of Hybrid Corn. Wallace's greatest contribution has been that of getting a large number of people enthusiastic about inbreeding and crossing of corn. He wrote many articles on the subject of hybrid corn which appeared in Wallace's Farmer. Wallace started the first commercial hybrid seed corn company in the Middle West in the mid-20's.

Development and Practical Production of Hybrid Corn Seed for Growers' Use*

Ordinary Reproduction in Corn

Corn is wind-pollinated in nature. The pollen is scattered at random on receptive silks. There is hardly one chance in a thousand that pollen which falls on a receptive silk was derived from the tassel of the same plant. Thus crossing is the rule rather than the exception. Any plant commonly sheds pollen from its tassels over a period of ten days to two weeks or more, a period long enough to assure, under most conditions, an abundance of fresh pollen for all silks of all ear-buds as the silks become receptive. The pollen germinates upon the silk, sending down a pollen tube through which the sperm reaches the egg to effect fertilization. Selecting an ear from a good plant is selecting a good female parent only, since each kernel on the ear may have been pollinated from a different male parent plant.

* In this section we are using freely as a reference and often quoting whole paragraphs directly from F. D. Richey's excellent Farmer's Bulletin 1744, "The What and How of Hybrid Corn".

Selecting Inbred Strains

In selecting inbred strains for the purpose of making hybrid corn seed, good plants of one or more varieties of corn are self-pollinated. Pollen is placed on the silk of the same plant from which the pollen was collected. The best of the resulting ears are planted, an ear to a row, and good plants within these rows again are self-pollinated, and so on for several generations. Each year only the ears from the best plants from the best rows are selected for continuing the various strains.

During this breeding period all pollinations are made by hand. Ear shoots are protected from air-borne pollen by means of a small bag clipped over the young shoot before any silks have emerged. Translucent material, such as special glassine bags, enables easy frequent inspection to detect emergence of silks. As soon as silks appear a manila bag is placed over the tassels of the same plant. Within twenty-four hours enough fresh pollen will have been discharged to pollinate the emerging silks. The manila bag is bent over and removed from the tassel as carefully as possible to avoid influx of air-borne pollen. The ear bud cover is removed only momentarily and the pollen from the same plant is poured over the silks. The manila bag is then clipped over the ear bud promptly to reduce chances of influx of air-borne foreign pollen. Sometimes another manila bag is clipped over the tassels to provide means for a second pollination twenty-four hours later, which gives added assurance of a full ear of kernels.

With a continuation of selective inbreeding as described above there is a marked increase from generation to generation in the uniformity of the plants within any progeny row, although the differences from row to row become more and more distinct. Some strains are discarded almost at once because of grossly unfavorable characters. Promis-

ing strains are continued and usually breed practically true for whatever characters they possess after about a half dozen generations of selective inbreeding.

All characters of varietal significance respond to selective inbreeding, characters which tend to favor quality, yield, dependability under adverse circumstances, resistance to or tolerance of diseases and insects. Every plant of any strain that has been fixed by adequate selective inbreeding is practically like every other plant within the strain. After this it is unnecessary to self-pollinate in propagating a strain. Under adequate geographical isolation from other strains, natural pollination between plants of a given strain is then essentially like self-pollination.

Among thousands of inbred strains that have been isolated in this way none has been found to our knowledge which gives a yield as great as the open-pollinated variety from which the inbred was derived nor as great as an F_1 hybrid using that inbred, according to W. R. Singleton of the Connecticut Agricultural Experiment Station. Of sweet corn inbreds developed in Connecticut, their C27 inbred approaches the parent open-pollinated variety in yield as nearly as any inbred of record. Also, under certain conditions, their C13 inbred will give a yield almost as great as Golden Early Market from which it was derived. The Purdue inbred gives an exceptionally good yield. P39 and Purdue Bantam are the inbreds which yield Golden Cross Bantam, the single cross hybrid sweet corn developed by Glenn M. Smith and which is by far the most important sweet corn available to American growers.

H. K. Hayes, Chief of the division of Agronomy and Plant Genetics of the University of Minnesota, long famous as a corn researcher and director of practical corn breeding, is confident, however, that considerable progress is being made in developing more vigorous inbreds.

With sweet corn and popcorn it appears that inbred lines more nearly approach their crosses in yield than with field corn, although Dr. Hayes knows of no inbred line that is as vigorous as a good hybrid combination.

Finding Good Hybrid Combinations

Since a search for vigorous inbreds, coincidental with hybrid corn development, has not disclosed inbreds of sufficient merit in themselves, among tens of thousands observed, it is probable that for many years inbreds will continue to be developed almost exclusively as the means toward good hybrid combinations.

The breeder of hybrid corn must develop great numbers of inbreds and must know the characters he is dealing with and their mode of behavior in inheritance. He must make large numbers of crosses and test large numbers of hybrids to find those strains that combine best when used together. The inbred strains producing the poorer hybrids are discarded. Those producing the best hybrids are again crossed and the hybrids tested more adequately. Eventually through continued elimination and selection a few inbred lines are found that combine to advantage. Finally some two or three combinations that have been among the best in a given locality during several seasons are placed in commercial production.

Sometimes a pair of inbreds is found which yield, when crossed, a hybrid that is dependable under a wide range of conditions. Golden Cross Bantam sweet corn, developed by Glenn M. Smith, is a notable hybrid of this nature.

Different Kinds of Hybrids

Inbred strains may be combined into several different kinds of hybrids. Thus the single cross or hybrid is between two

inbred strains, the three-way cross involves three strains, the double cross four strains, and the top cross involves one inbred strain and one open-pollinated variety. Each of these has certain advantages and disadvantages or fits into the corn-breeding program in a particular way.

The simplest of these hybrids is the single cross, or hybrid between two strains. Thus, designating the female parent first in the customary way, B × A designates the single cross of strain B pollinated by strain A. The seed of the cross is that produced on the plants of strain B and usually will not appear noticeably different from self-pollinated seed of B. The vigor of hybridity becomes evident, however, shortly after germination begins if the crossed seed is planted.

The three-way cross is the F_1 hybrid of a single cross between two inbred strains and a third inbred strain. It is customary to use the single cross as the female and the third inbred strain as the male parent in producing a three-way cross. Thus, (B × A) × C designates the hybrid from a single cross B × A pollinated by strain C. The crossed seed produced on the vigorous B × A plants is superior in quality and quantity to that produced on inbred plants as in single crosses.

Double crosses are hybrids between the F_1 hybrids from two single crosses, involving four different inbred strains. Thus, the double cross or hybrid (B × A) × (C × D) designates the hybrid of the single cross B × A pollinated by the hybrid of single cross C × D. Here, both male and female plants are vigorous hybrids. The seed quality and production are high, and there is every possible assurance of abundant pollen from the male parent, which is not true when this parent is an inbred strain.

The cross of a commercial variety and an inbred strain has been variously designated as a top cross and inbred-sire cross. In limited experiments some such crosses have yielded more than ordinary varieties but less than comparable double crosses.

The make-up of double-cross hybrid seed is illustrated in Figures 3 and 4. The four ears labeled B, A, C and D (Fig. 3) represent the product of the inbred parent lines. If these are self-pollinated they will reproduce ears like those shown year after year. Seed from ear B, however, when pollinated with pollen from the plant producing A, produces the single cross B × A, shown immediately below its parents. Similarly the single cross C × D is produced from seed on ear C that was pollinated by pollen from plants producing D ears. The ears on the B × A plants, cross-pollinated by pollen from C × D plants, then provide the first-generation seed of the double cross (B × A) × (C × D), which is used in growing the ordinary corn crop. The ears at the bottom of Figure 3 represent what is produced in such commercial fields. The ears produced on the C × D plants grown to furnish pollen are used for feed or commercial corn. The seed from these ears may be planted to produce pollen-furnishing plants for another crossing block the next year. Such seed is referred to as advanced-generation seed and is equal to first-generation seed for producing pollen parent plants, but these will yield on an average only about two-thirds as much grain as the first generation.

The situation is perhaps clearer from Figure 4, which shows the system of crossing beginning with the inbred plants. Plant B is pollinated with pollen from plant A, and plant C is pollinated with pollen from plant D. Seed from these cross pollinations produces the single-cross plants B × A and C × D shown immediately below the parents. Plant B × A pollinated by plant C × D produces the double-cross hybrid seed

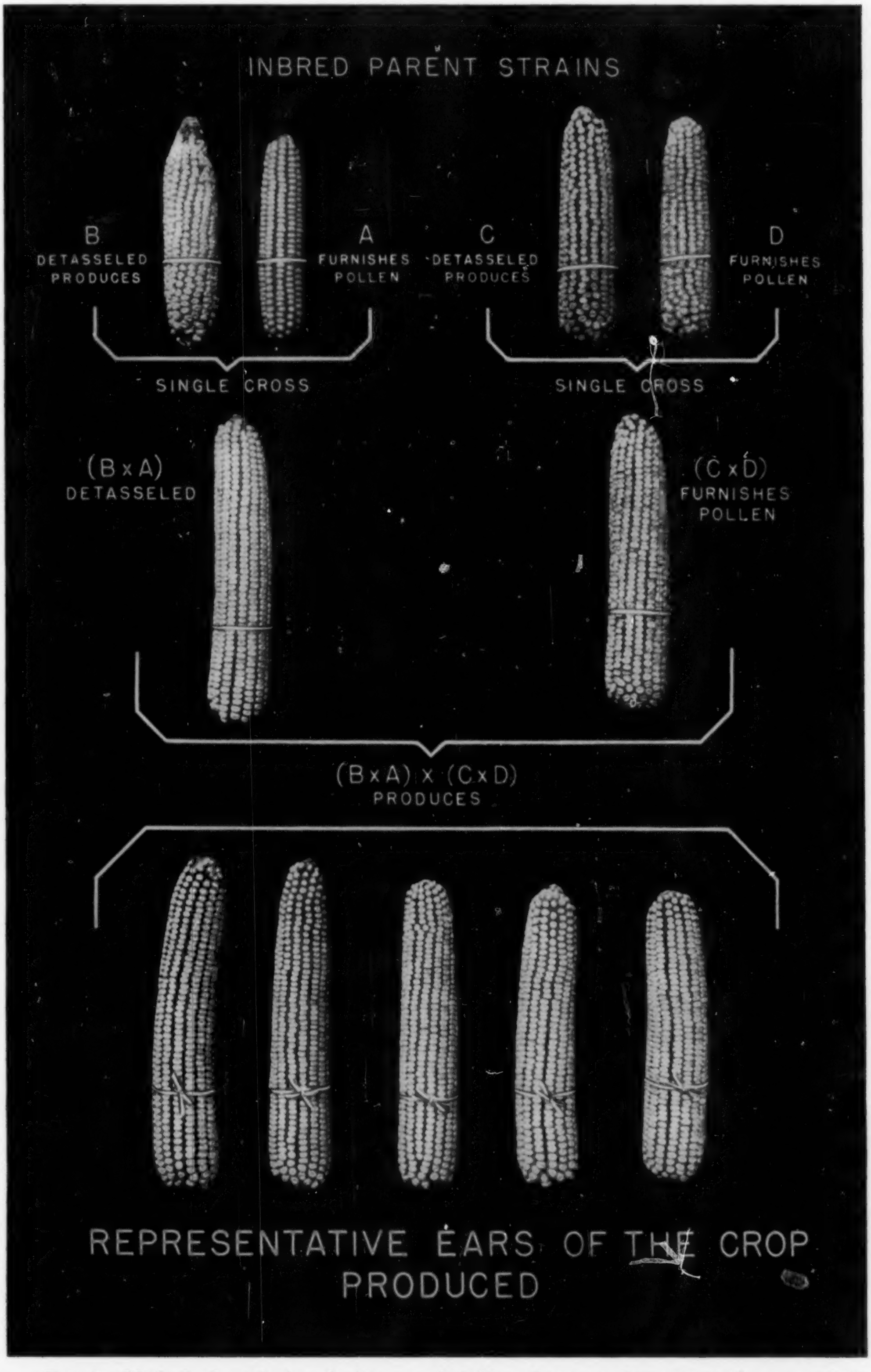


FIG. 3. Method of producing double-cross hybrid seed-corn, and representative ears of the crop produced from hybrid seed. *Farmers' Bulletin No. 1744. Courtesy U. S. Dept. Agr., Bur. Pl. Ind., Soils and Agr. Eng.*

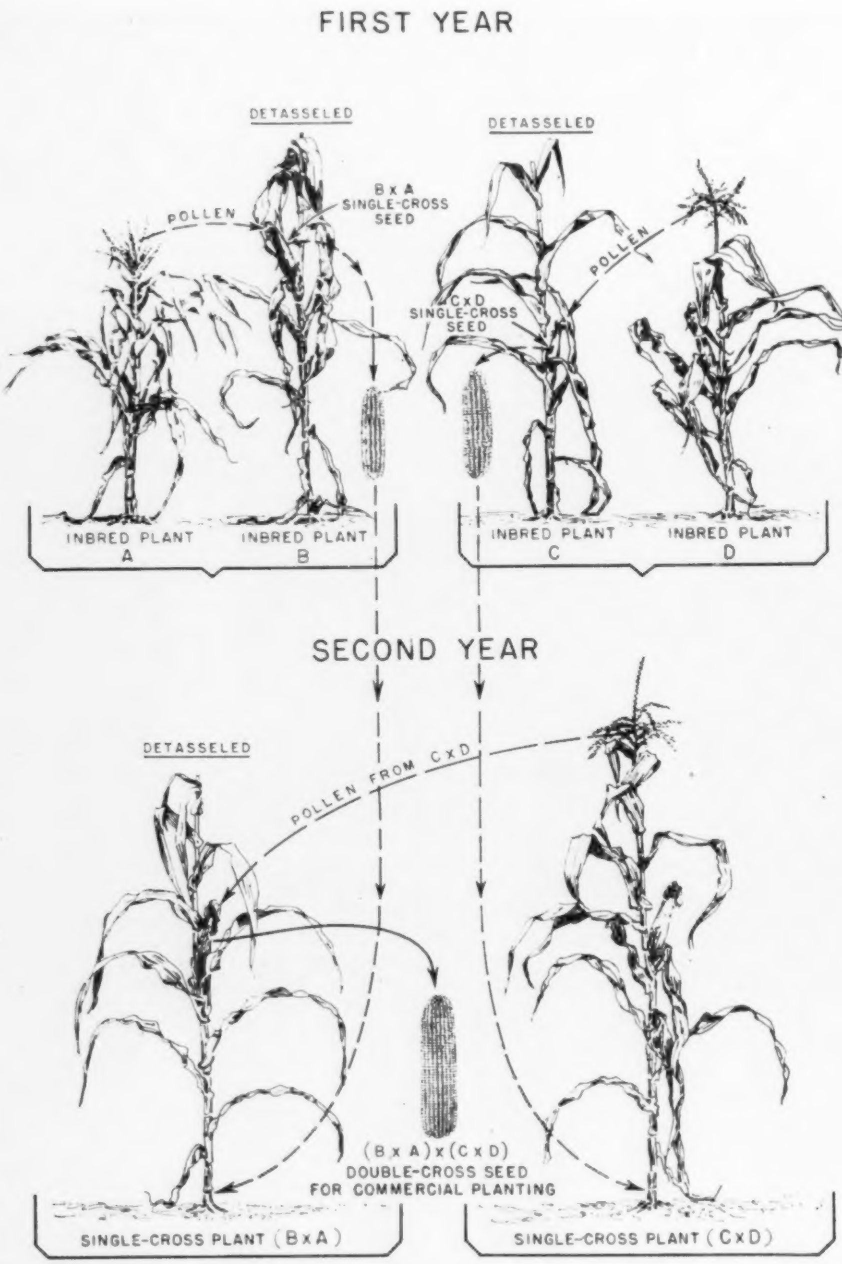


FIG. 4. Diagram of method of crossing inbred plants and of crossing the resulting single crosses to produce double-cross hybrid seed. *Farmers' Bulletin No. 1744. Courtesy U. S. Dept. Agr., Bur. Pl. Ind., Soils and Agr. Eng.*

represented in Figure 4 by a single ear. It is this seed that is planted to produce commercial corn.

Advantages of Different Hybrids

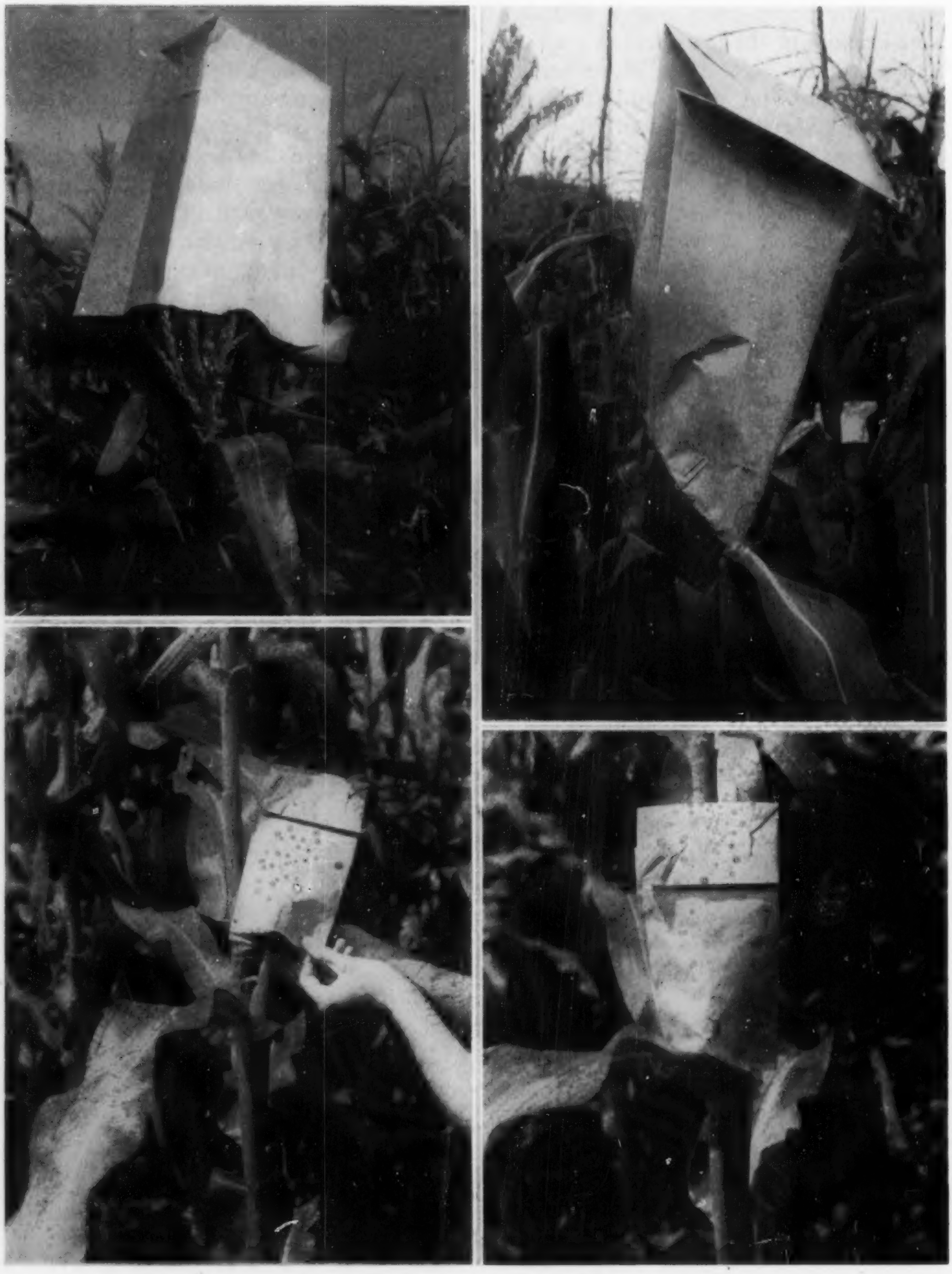
Any of these hybrids can be used in planting for commercial corn produc-

tion. The single cross is at a disadvantage because of the low yield of seed and its consequent high cost. Moreover, the irregular size and shape and the generally small kernels of present field-corn inbreds make the commercial utilization of single crosses impractical. Single crosses produce the most uniform plants and ears of any of the hybrids. They accordingly have special value when uniformity is most important. Thus uniformity is highly desirable in sweet corn for canning, and, to some extent, single crosses between inbred strains are being used commercially for this purpose. In field corn, however, three-way and double-cross hybrids will be used unless much better inbred strains are developed than are available at present.

The three-way cross has no particular advantage over the double cross. It is slightly more uniform but not importantly so. Probably the main reason for the production of three-way crosses commercially has been that it was easier to find three reasonably good inbred strains than four. Another advantage of the three-way over the four-way cross is that it requires fewer isolated plots. The serious disadvantage of the three-way cross is that an inbred strain must be relied upon to supply pollen for the cross. Unless an inbred that can be counted on for this purpose is available, the three-way cross is impractical. Even a reasonably good pollinating strain requires a somewhat larger proportion of male parent plants with a somewhat higher cost of seed production. For the present and for some time to come, therefore, the double cross seems to be the most practical source for hybrid seed corn.

FIG. 5. A typical production field that will yield Hybrid Corn seed for growers' use. Note the tasseled rows that provide pollen for the larger number of detasseled rows from which Hybrid-Corn seed will be harvested for sale to corn farmers. *Photo courtesy Funk Bros. Seed Company, Bloomington, Illinois.*

The only value of top crosses of field



STAGES IN ARTIFICIAL SELF-POLLINATING OF CORN

FIG. 6. (*Upper left*). Paper bag being placed over staminate tassels preparatory to pollination.

FIG. 7 (*Upper right*). Paper bag fastened over staminate tassels.

FIG. 8 (*Lower left*). Paper bag being placed over ear shoot before the silks emerge.

FIG. 9 (*Lower right*). Paper bag fastened over the ear shoot.

STAGES IN ARTIFICIAL SELF-POLLINATING OF CORN

FIG. 10 (*Upper left*). Paper bag removed from ear shoot one day after Fig. 9, the silks grown out and being cut off, the decapitated shoot to be covered by a glassine bag.

FIG. 11 (*Upper right*). Silks grown out of decapitated shoot one day after Fig. 10 and visible through glassine bag.

FIG. 12 (*Lower left*). Glassine bag removed from ear shoot one day after Fig. 10, and emerged silks being pollinated from bag of Fig. 6.

FIG. 13 (*Lower right*). Paper bag placed over self-pollinated ear of Fig. 12. This completes the self-pollinating operation. *Photos 6–13—By courtesy of the Conn. Agr. Exp. Sta.*

corn for commercial use at present appears to be in the fact that it is easier to find one inbred that will combine well with some standard variety than to find three or four inbreds that will produce a good three-way or double cross. Experimentally, top crosses provide an efficient means for the preliminary testing of inbred strains for later use in other hybrid combinations.

The user of hybrids need not worry about whether he is getting single-cross, three-way cross, or double-cross hybrid seed, if it is of good quality (quality including size and shape suitable for machine planting) and if it has a definite record of productiveness in his community. The producer of hybrid seed will be governed largely by his individual facilities and the inbred strains that are available to him.

Producing Hybrid Seed Corn

Regardless of what kind of hybrid seed is involved, only the first generation of the hybrids should be sold or used for commercial planting. Only from this generation, *i.e.*, the seed that was actually cross-pollinated by another strain or hybrid, is the maximum benefit of hybrid vigor to be obtained. The second generation of any double-cross hybrid, that is, the seed produced by the first generation, may be expected to yield from about 10% to 25% less than the first generation, the exact decrease depending upon the particular hybrid. It is this fact that necessitates producing the hybrid anew for each season's use.

Hybrid seed is produced for commercial use by growing rows of the two parents in an isolated field and detasseling the plants of the female parent. In general, a field for this purpose should be not less than 40 rods from other corn unless there are buildings, trees, or other barriers between, or unless the two fields do not tassel at the same time. From two to four rows of the strain to become the female parent can be planted to every row of that which will be allowed to function as the male parent. If an inbred strain is to furnish pollen, it is safer to plant not more than two rows of the female parent. If a vigorous hybrid is to be the male parent, four rows of the female parent can alternate safely with one row of the pollen parent in the corn belt. As the seed comes only from the female-parent rows, this is a good reason for using a vigorous male parent.

Detasseling at Blossoming Time

During blossoming time the field is gone over at regular intervals, and all tassels are pulled from the female-parent plants before they shed pollen. With few exceptions the tassels emerge enough so that they can be seen before they begin to shed. A quick upward pull at this time takes the tassel out cleanly without damage to the plant. Tassels pulled too early are likely to bring with them part of the top of the plant, with some damage. On the other hand, it is not safe to wait too long lest the tassels begin to shed before they are pulled. Therefore, it is necessary to go over the field practically every day until detasseling is completed.

Material Value of Hybrid Corn

The hybrid corn technique devised incidentally at an extremely modest cost at a research station devoted to experimental study of evolution has made modern corn breeding a highly specialized science. State and federal experiment stations pursue various courses in seed-breeding aid of the corn-growing industry. Large hybrid corn companies are, however, becoming more and more self-reliant with large staffs of highly trained specialists capable of meeting within natural limitations the seed requirements of the gargantuan corn-growing industry.

Corn hybrids are tailor-made to meet cultural and industrial requirements.

Field implements and processing plants are designed for most efficient planting, harvesting, curing and grading. Truly, American corn-growing, with still greater advances in view, has already reached a peak of efficiency undreamed of in the earlier life of many of us who enjoy the tremendous benefits of the marvelous commodity Hybrid Corn.

The percentage of total corn acreage planted with Hybrid Corn in the United States between 1933 and 1944 increased from 0.1% in 1933 to more than 50% in 1943, and the acreage continues to increase yearly. By 1946 some of the most important corn-growing areas had increased their acreage of Hybrid Corn to almost their entire crop.

Following the harvest of 1943, M. A. McCall of the United States Department of Agriculture said in commenting upon the use of Hybrid Corn seed: "Never until the last two years has the United States grown more than 3,000,000,000 bushels of corn in each of two successive years, and never before on as small an acreage. This is almost certain to stimulate even wider use of intensive methods with other crops".

Mr. McCall went on to say that on the basis of hybrid corn acreages and yield during the preceding six years and the average yields during 1923–32 (the last normal 10-year period before Hybrid Corn came in), it can be estimated that Hybrid Corn added 629,000,000 bushels of corn to our total crop in 1942, and 669,000,000 bushels in 1943. This is equivalent to adding each year almost one-fourth of a normal crop of corn in years before Hybrid Corn came into use.

Hybrid Corn Justifies Research in Pure Sciences

The tremendous success of Hybrid Corn in terms of practical gains derived from research in pure science has served toward encouragement of research in related and unrelated fields. Corn has been the object of intensive genetic research in well-staffed and well-equipped laboratories whose findings have advanced greatly our knowledge of plant genetics.

Important progress has already been made in achieving and utilizing hybrid vigor similarly in other kinds of plants. Hybrid livestock and poultry are being studied and some have demonstrated remarkable superiority over parent breeds.

In calling attention to the importance of adequate national support of scientific research, Dr. L. J. Stadler of the University of Missouri said, in part, while testifying before a sub-committee of the Committee of Military Affairs of the United States Senate on the subject of Science Legislation:

> We know from the crop estimates of the United States Department of Agriculture what fraction of the corn planted in each county was planted from hybrid seed, and we know from numerous and widely distributed field experiments the comparative performance of different strains of corn when grown side by side under identical conditions. In these experiments adapted hybrids consistently outyield the varieties of corn formerly grown, with an average margin of over 25 percent.
>
> This is an increase in yield which costs nothing except the added cost of producing the special type of seed and the added cost of harvesting a larger crop. In practice the seed is commonly produced by specialized seed growers, and the production and sale of hybrid seed corn has now become an industry with an annual turnover of about \$75,000,000.
>
> A conservative estimate of the increase in national corn production during the four years 1942–45, due to the partial use of hybrid corn is 1,800,000,000 bushels. The money value of this increase on the basis of farm prices per bushel is more than \$2,000,000,000.
>
> It is, therefore, no exaggeration to say, speaking in terms of the overall national economy, that the dividend on our research investment in hybrid corn, during the war years alone, was enough to pay the money cost of the development of the atomic bomb.

Manioc—*A Tropical Staff of Life*

A plant which in one form contains deadly prussic acid and in other forms nourishes thousands of primitive people and furnishes tapioca to modern man.

ROBERT W. SCHERY
Missouri Botanical Garden

Importance, Preparation, Use

PERHAPS it's a grain? No. A potato or bean? Certainly not. Well then, what other form of vegetable life may be so linked with man's daily existence as to be termed a "staff-of-life", to bear the burden of furnishing the basic food in the diet of many millions of men? Dwellers in the tropics—in the Americas from Mexico south to Paraguay—many of whom would scarcely recognize a potato and whose only acquaintanceship with important cereal grains is an occasional planting of maize, can tell you. It is manioc, the tuberous root of *Manihot esculenta* Crantz (*M. utilissima* Pohl.). Yes, manioc, or mandioc, or cassava, or yuca, or any of several other Indian- or Spanish-sounding titles, is the name of the most important—and frequently the only—primary source of sustenance to thousands of interior-dwelling Latin Americans and to their tropical brethren of even more distant lands. Surprising this may seem to North Americans, for most of us have never seen manioc nor even become familiar with its name, and little detail concerning it has been published north of the Spanish-speaking republics. Yet, unknowingly, most of us have eaten it, in a specially prepared form, as tapioca.

Amongst the Latin countries to our south manioc is known in an endless selection of varieties, many of which are poisonous to varying degree, for the manioc species contains a poisonous glucoside related to prussic acid. Selection of "sweeter" varieties, those graced with less of the toxic glucoside, permits of more ready preparation than do the "bitter" maniocs, although I know of none that is not cooked or otherwise made edible by man's hand. No hard and fast boundary exists between "sweet" and "bitter" maniocs, all stages of intermediacy being found. Quite probably growing conditions—soils, rainfall, elevation, and the like—are as important in determining the poisonous character of a manioc as are the vague hereditary factors of varietal differentiation, or even more so. Basically two methods are followed to make palatable this essentially non-edible raw root. The simplest—one often used for sweet maniocs—consists of mere boiling in water as we might boil potatoes or sweet corn. Such boiling drives off or changes to inocuous form the small quantities of prussic acid or glucosidal poisons, just as would fermentation or extraction by mechanical means. A sticky, starchy, fibrous vegetable results, with a consistency as "heavy" as incompletely cooked macaroni. It retains its natural shape, much that of a very slender sweet potato. As such it is consumed, a staple item of the diet in outlying areas of southern Brazil, Paraguay and the Andean countries northward.

But in northern and eastern Brazil, as perhaps elsewhere, the second and more elaborate mode of treatment gives

a readily handled staple, sacked and sold much as is our wheat flour. There "farinha",[1] the final pulverized form of manioc, is the cheapest, omnipresent, and frequently the sole food for scores upon scores of native peoples—peoples generally inadequately fed, to be sure, from the dietary standpoint. I have encountered distant interior villages where the only food to be purchased was farinha. This dry form, plus whatever windfalls in the way of wild game might befall the villagers, was the complete diet in the village at the time.

Farinha in northeastern Brazil is made by first rasping the tuberous manioc roots in primitive local "mills". A horse or oxen yoked to a rotating beam continuously circles the hand-fashioned wooden gear, supplying power. A series of gears or pulley-belts ultimately rotates a wooden roller at high speed. Studs of nails, driven firmly into the roller on various planes, whir threateningly as an outer blur to the roller. The manioc root is pushed against the whirring spikes, and is shredded to bits by the whirling studs, much as excelsior might be torn from soft woods. The mushy mass of shredded manioc is then carried to a crude press, generally consisting of a wooden box with plunger. The plunger is forced against the box by a lever weighted with stones, or by a

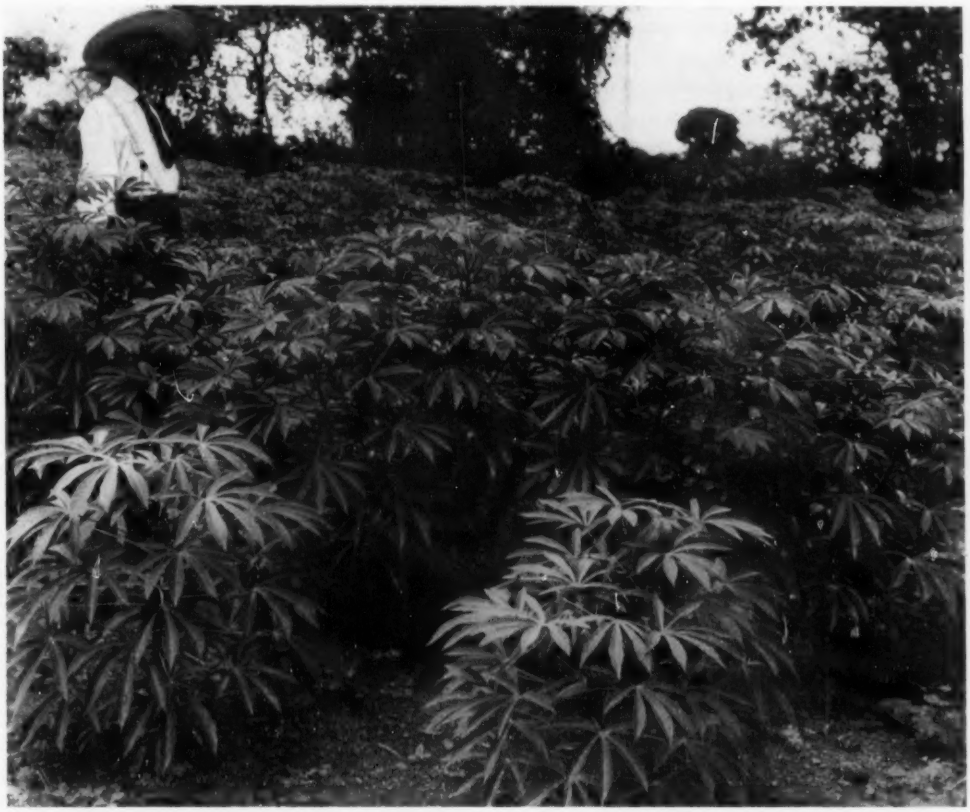


FIG. 1. Young plants of manioc or cassava, *Manihot esculenta*, the source of farinha and tapioca and used industrially in laundry and sizing starches, adhesives, simple sugars, syrup, alcohol, acetone and animal fodder. (*Courtesy of the New York Botanical Garden.*)

[1] A Portuguese word, pronounced fah-reén-yah, meaning "flour."

gigantic wooden screw, itself tightened through human sweat in lands where a blistering tropic midday drives all creatures to the shelter of shade. This pressing expels liquid from the mass, including most of any poisonous principles. Sometimes the shredded manioc is merely drained in basket-like sieves, where specially designed presses are not to be had. Farinha from such drained manioc is just as palatable as that more conveniently made after expression, for in final drying any poison, like water, is completely expelled. I have not seen the

FIG. 2. Foliage and tubers of manioc. *(From L. H. Bailey, Cyclopedia of American Horticulture. By permission of The Macmillan Company, Publishers.)*

expressed liquids retained for fermentation—to make, strangely enough, a drink poisonous only as is its alcohol—as is the custom in regions to the west. The manioc mass is finally spread on flat tins, above a wood or charcoal fire, where it is turned and stirred until dry, a process similar to that followed in making tapioca. The result is farinha, coarser than our wheat flour, resembling somewhat North American cornmeal. This is the staff-of-life in thousands of unnamed out-of-the-way places.

In some localities, usually mixed Indian communities near Amazon country, an interesting method of expelling the manioc juices was developed. The tuberous roots, after proper soaking and cleaning, are cut or shredded by hand and then dumped into a gigantic cylindrical "chinese finger-lock" woven from palms or other fibrous material. This six-foot tubular "finger-lock" operates the same as do the novelties known to many Americans: pulling or stretching lengthwise alters the position of the fibers, narrowing the tube and gripping its contents ever more firmly. The tube with its manioc content is hung from a suitable support, and tension is applied at the base by simple leverage, created from a pole and human endeavor. The narrowing of the tube squeezes out the juices from the contained manioc—juices often collected and saved for purposes previously hinted. Those same juices, concentrated through boiling, form West Indian pepperpot, an ingredient of our better known meat sauces. In other localities special grating boards have been devised, solely for shredding manioc. Story has it that white man first discovered diamonds in the Guianas in a native manioc grating board.

All these manioc foods are to me rather tasteless, being almost exclusively of a starchy nature. In South America boiled manioc is usually eaten along with beans, rice and maize, if and as they are available—usually seldom in poor interior villages. Salted and in combination with other foods it is not unpalatable. Farinha is customarily eaten dry, except where resource permits its preparation as a delicacy in the juices or grease of grilled meats, usually with an onion seasoning. I find it quite palatable, both in the latter way, and in the former if some sort of sauce, gravy or broth is available. Eaten dry, by the handful—the common way in less affluent families—one can not anticipate

much gustatory pleasure. But in a land where farinha is usually available at but a few cents per pound, families of the interior, living on less than 25 cents per day, can afford little else.

Botany

Manioc is a small shrub of the *Manihot* genus, an immense genus which includes several rubber-producing species of significant economic importance. In Brazil alone, literally hundreds of species of *Manihot* are known. That most described species and varieties are "good" is doubtful. I have seen marked variability and apparent hybridization in several well recognized rubber-producing species. Similarly, hundreds of varieties of edible maniocs, mostly of the *Manihot esculenta* species, have been recorded, from Paraguay to Colombia in South America, from Jamaica and the West Indies, from East Africa, India, Ceylon, Madagascar, the Philippines, and even from Florida. Few of these have been preserved for herbaria, and little comprehensive study has compared or related varieties of one area with those of another. Most of these varieties have undoubtedly arisen since manioc has been under cultivation, and many are only locally recognized

A member of the spurge family, manioc is a relative of the spine-studded, stinging jatrophas, the common poinsettia, and the Pará rubber tree—all producing a milky juice or latex. Manioc itself much resembles its lactiferous brethren of *Manihot*, but is only slightly or scarcely milky. Its palmately lobed leaves are like those of its relative, the castor bean, and are quite variable. Its flowers, typical of the Euphorbiaceae, may be deficient in either male or female elements. It seems to be quite tolerant of soil types, is able to endure nearly complete neglect, and thrives relatively free from disease or insect pests.

Among all the Euphorbiaceae, only *Manihot esculenta*, along with one or two other species, produces the tuberous roots which make it important the world over. These roots vary from variety to variety, from place to place and from time to time. Young roots harvested about six months from planting are reported to contain up to 6% sucrose as well as the normally high percentage of starch. Older roots, up to about 18 months from planting, give optimum yields and abundant starch. Such roots frequently consist of 30% or more starch by weight. Very old roots become more or less lignified and unsuitable for ordinary food or commercial purposes. In all roots the epidermal and cortical regions seem to contain most of the poisonous glucosidal or prussic acid principles. The pithy center, relatively free of these poisonous elements, contains most of the starch. Thus in preparation of commercial starch, peeling or fermenting off the outer layers, as is commonly done, little diminishes the yield of starch and at the same time permits a purer dirt-free commercial product.

Cultivation

Manioc is typically propagated by stem cuttings, a process the simplicity and ease of which appeals to the not overly ambitious tropical peoples, whose agricultural work must be done by sweat of the brow during tedious hours in the field. Moreover, stock for cuttings always grows available, and no planting rush need disturb the tropical tranquility; what isn't planted today. . . . Planting methods in the interior are those of generations past. In northeastern Brazil forest is burned during the dry season, and then before the life-giving rains come, sections of manioc stem are planted in the burnt-over area. Crude cultivation with heavy iron hoes may follow as needed, or sometimes the manioc may be left to fare for itself. In as little as six months under good

growing conditions a harvest may be obtainable. Plants with their roots are torn or dug from the ground. Roots destined for the farinha mill are cleaned and peeled prior to being shredded. Others may be stored in piles, or even left in the ground until needed. One of the great assets of manioc as a food and commercial plant is its remarkable keeping quality. And yields may be as high as 20 tons to the acre, while plants may be grown as close as a yard apart (10,000 to the hectare).

Native to the Americas, possibly originating in Brazil, manioc is unknown in the undomesticated state. Its ancestral form, from which it was first cultivated by primitive man in some ancient bygone era, is not known. Yet modern man, in the form of the sixteenth-century Portuguese explorer, finding manioc cultivated by Brazilian Indians, realized its worth and soon carried it to tropical Africa. Thereafter manioc spread throughout the world tropics, especially by the hand of British and Dutch colonizers, to become a food of primary importance in all tropical lands meeting its rather exacting temperature requirements. And today, perhaps, both Africa and the Dutch East Indies surpass South America in production of this food-gift from the Western World, an original gift supplemented by subsequent introductions of newer varieties.

Modern Industrial Uses

Manioc is of importance not alone for its value as local food, but also as a tropical export item to Europe and North America. In these latter continents it is sought for preparing food, and laundry and sizing starches; for making glue and postage stamp adhesives; as a source of simple sugars, syrup, alcohol and acetone; as animal fodder; and for human consumption as tapioca or products of manioc flour.

In preparing industrial starches, the chief non-nutritional use for manioc, the "tubers" are treated in the early stages much as in the making of farinha. By various means the thoroughly cleaned and washed roots are shredded or crushed, during which operation individual cells are broken apart. Only by such breaking of the cells can the minute starch grains contained within escape. After straining fibrous material from the crushed mass, the remainder is streamed in water to appropriate settling basins. Settling usually serves to separate the starch grains from the watery medium, after which the supernatant liquor is decanted off. The starch sediment is then dried, following additional washings if needed. Manioc starch has been reported highly desirable for sizing cotton thread prior to weaving, being more pliable and infiltrating the thread better than does corn starch.

Stirring or shaking manioc starch on a heated plate at controlled temperature until the starch swells and masses into pellets of the proper size, produces the common tapioca of commerce. The starch is partially converted to sugar during the process, as well as rendered somewhat gelatinous. Starch for various other food purposes is often known in the trade as "arrowroot", and is said to be especially digestible. Mention has already been made of "pepper-pot" meat sauces, prepared from boiling down expressed manioc juices from which starch has been removed, and to which are added flavorings and pepper. Any poisonous elements originally contained are rendered innocuous by repeated boilings. Boiling down juices from particularly sugary varieties produces a molasses-like substance, said to be highly esteemed in Paraguay.

Manioc may also serve as a source of alcohol, primitively produced among aborigines by allowing the expressed juices to ferment. Some of the most colorful tribal customs involve drink-

ing alcoholic beverages produced from manioc, the juice of which is frequently obtained by mastication and expectoration. More modern methods of hydrolizing starches of the starch-rich manioc root to sugars for subsequent fermentation would produce more certain industrial results and complementary higher yields of alcohol.

Raw manioc roots, or manioc wastes after expression or starch removal, are usable as cattle feed. Given alone, such feed leads to dietary unbalance in the animals, lacking, as it does, needed protein elements. But being low in protein, manioc is thought by many to drain the soil less severely of nitrogenous materials than do many other crops used for cattle feeding. Grown in conjunction with proper leguminous forage, dietary balance for cattle should be attained, while the soil could likewise be expected to benefit from growth of the legume.

Thus this starch-rich food-for-millions (manioc produces more utilizable starch per acre than any other known crop), a true "staff-of-life" amongst many ill-nourished tropical populations, also helps in its minor way to nourish the economy of temperate latitudes.

Utilization Abstracts

More Antibiotics. Recent investigations indicate that wild American ginger, formerly grown for its cathartic and emetic qualities, possesses two antibiotics, one of which is more active than the other and effective "against pus-forming gram-positive bacteria such as staphylococcus, streptococcus and pneumococcus, but has no effect on germs in the intestines". Burdock and garlic also seem to have promise as medicinals, and in 1921 Japanese scientists isolated a substance, protonanemonin, from buttercups, "which was found to be a potent antibiotic, but too toxic for human use". (*Anon., Chemurgic Digest 5(13): 234. 1946*).

Oil of Rue. A little-used though nevertheless commercially produced vegetable oil is that of the genus *Ruta*. Small quantities are employed in flavoring materials and in certain types of perfumes and soap scents. The oil is obtained by distillation from several wild species in Spain, North Africa (mainly Algeria), Sicily, Sardinia and France (mainly Provence). The principal producing regions are the Provinces Badajos, Cádiz, Seville, Cordoba and Huelva in Spain. Wild plants are collected in July and August during the blooming period and distilled in field stills without previous drying. The pollen of the plants causes skin blisters, on susceptible workers. During recent years Spain produced from two to twelve tons of rue oil annually. (*E. Guenther, Am. Perf. & Ess. Oil Rev., May, 1946*).

Vegetable Oil Exports from Brazil. Vegetable oil exports from Brazil in 1945 amounted to 43,264 tons as compared with 34,668 tons in 1944, surpassed only by the figures of 1941. More than 90% of the oils came to the United States, consisting of cottonseed oil, oiticica oil, castor oil, coconut oil, babassu oil and others of less importance. (*Anon., Brazilian Bulletin, Brazilian Gov't Trade Bur. 3(62): 1. 1946*).

Mulberry Trees in Brazil. The silk industry in the State of Sao Paulo, Brazil, has increased the planting of mulberry trees, used for raising the silk-worms, from 15 million in 1941 to more than 250 million in 1946. (*Anon., Brazilian Bulletin, Brazilian Gov't Trade Bur. 3(62): 5. 1946*).

Barley. "Classification of barley varieties grown in the United States and Canada in 1945" is the title of Technical Bulletin No. 907 of the U. S. Dept. of Agr., issued in May, 1946. It contains 190 pages, 93 figures, and deals with the morphology and taxonomy of 140 varieties of barley. (*E. Åberg and G. A. Wiebe*).

The Cork Oak Tree in California

WOODBRIDGE METCALF
Extension Forester, University of California

There are 5,000 trees in various parts of the State, planted at various times, and recent experimental strippings of the largest have yielded 600 to 1,000 pounds of high quality cork per tree. Does this presage an American cork industry?

Historical

THE cork oak tree, *Quercus Suber* L. is native in the vicinity of the Mediterranean Sea where it is a prominent feature of the vegetation in about five million acres of natural forest situated in Portugal, Spain, Italy, North Africa, Greece and the Mediterranean islands. Like the other evergreen oaks, it is quite variable in leaf, flower and acorn characteristics, and some authorities have separated out one variety known as *Q. occidentalis*, for which the identifying characteristics are too obscure for exact determination under American conditions. Holm oak, *Q. Ilex* L., is usually associated with cork oak throughout these natural forest stands, both trees having sturdy trunks, heavy spreading branches and broadly rounded crowns of dense, holly-like foliage, similar to that of the coast live oak, *Q. agrifolia* Née, and highland live oak, *Q. Wislizenii* DC., of California foothills.

The outer bark of cork oak, known commercially as "Corkwood," has been harvested from these Mediterranean forests for many years without injury to the trees which can be stripped at about ten-year intervals until well over one hundred years old. The highest grade corks for wine bottle stoppers are made from third to sixth stripping sheets of cork from trees 50 to 80 years old, as this cork has the minimum volume of lenticellular pore spaces in it and is, therefore, of very uniform quality. During the past quarter century cork has gradually increased in industrial importance because of its qualities of lightness, resilience under pressure, imperviousness to liquids and gases, even in composition form, and its remarkable resistance to the passage of heat, which has given it a position of primary importance in the insulation field.

These with many military and naval uses have resulted in steadily increased demands for cork until the world output is now said to be in excess of three hundred thousand tons per year, of which between 50% and 60% is used in the United States. This demand is now at the rate of one ton for each 17 acres of natural cork oak forest and may be approaching the maximum possible continuous output from these stands. This is based on a conservative estimate of an annual yield of 200 pounds of cork per acre of well managed cork forest on good soil in the better parts of its natural range. It is thus evident that the United States is using the entire output of cork from 1½ to 2 million acres of forest, all of which is across a wide ocean from our shores. During World War II cork was a material of critical military importance, and the supply had to be carefully rationed. Thus an emergency supply of this material on trees growing within the limits of this continent may be of very great importance in a future

emergency. The cooperative cork oak program which has been under way in California since 1940, has in view the creation of such an emergency supply.

The University of California, California State Division of Forestry, California Forest and Range Experiment Station, and the Western Crown Cork and Seal Corporation have jointly sponsored this project and proceeded along the following lines:

1. Listing of all cork oak trees and plantations in California as a basis for collection of sufficient acorns to carry on the growing of trees and the determination of the quality of cork produced by California trees.

2. Collection of acorns for propagation and free distribution of from 20,000 to 30,000 cork oak trees per year; with tests for storage, germination, nursery and planting technique to give the best results; and shipment of acorns as required to start the program in other states.

3. Stripping of sufficient trees of various sizes throughout the state to determine amount and quality of California grown cork, feasible stripping dates and tools and methods of carrying on the work with minimum damage to the trees, many of which were privately owned and prized as ornamentals.

4. Determination of geographical and altitudinal limits within which the cork oak may be successfully grown with moderate attention and irrigation.

5. Observations on insects and diseases affecting cork oaks in California.

6. Genetic studies on different races of cork oak and selection of the more desirable strains for high production and good quality. Tests of possibility of hybridizing *Q. Suber* with *Q. variabilis* Blume and perhaps other species of oaks.

7. Check on the possibility of growing Amur Velvet, *Phellodendron amurense* Rupr., Formosa cork, *Quercus variabilis*, and any other cork-producing trees in this region.

After six years of work we can now report satisfactory progress along most of the lines indicated above.

Records of Cork Trees Growing in California

Some preliminary studies of cork oaks growing in California were made by the writer in 1929 and recorded in a publication issued that year at the request of the Sacramento Region Citizen's Council.[1] With this as a beginning and with the assistance of a number of interested agencies and individuals, it has been possible to record the location and size of approximately 5,000 cork oak trees of moderate to large size which are growing in some 30 California counties. About 2,000 of these are in Los Angeles County, and special thanks are due to Mr. Averill Barton of the Los Angeles County Forestry Department for the very complete record he compiled of all such trees growing in county territory during 1941. With this and similar records which are being kept in a card file, it has been possible to contact owners of trees to arrange for collection of acorns and test stripping of cork where they did not object to having this done.

An interesting feature of these records of early plantings is the fact that no trees were found to have been planted during the Spanish period. Many of the oldest trees apparently go back to the shipment of acorns brought in to San Francisco by the Patent Office in 1858, though there is a possibility that the large trees on the J. T. Kiser Ranch, south of the town of Sonoma, may have been planted three or four years earlier. It seems probable that the Spaniards attempted to bring in the cork oak along with the olive, grape and other things they started here; but from what we now

[1] "Cork Oak—A Forest Tree With Possibilities for California". Reprint from October 1929 Bulletin of the State Department of Agriculture. Reprint from State Printing Office, Sacramento, 1929, by Woodbridge Metcalf.

know of the storage requirements of cork oak acorns, these apparently died during the long, slow voyage necessary in the period prior to 1850. When transportation was speeded up with the introduction of clipper ships more of the acorns came through in viable condition. It seems fairly certain that the Kiser Ranch trees, which are now between 45 and 50 inches in diameter, were planted in the 50's, and that the three fine, tall cork oaks at Tuttletown, Tuolumne County, grew from the above shipment of acorns, as they are reported to have been planted in 1858. The tree at Clarke's Nursery, Santa Clara County, may have been from this same lot of acorns but is much smaller than the other trees. Some trees evidently go back to the 60's and 70's, and the tree at the old mining town of Todd's Valley near Forest Hill, Placer County, may be one of these. It has made good growth under natural conditions at 2,700 feet elevation but is said never to have produced a crop of acorns. It is locally reported that A. G. Read, storekeeper at Todd's valley for many years, got cork oak acorns from France in 1870 and that the tree grew from one of these. It was 39 inches d.b.h., 50 feet tall and 70 feet across the crown in 1942, and produced cork of good, firm quality. It is growing at a higher elevation than any other tree in California. There are well developed trees of cork growing along the coast from San Diego County (Balboa Park) to the most northerly tree which is old but quite misshapen and grows on a moist flat near Rhonerville, Humboldt County. It has never produced a crop of acorns. In the interior valleys there are good specimens from Riverside County on the south to Butte County on the north.

FIG. 1. One of the four large cork oak trees on the Kiser Ranch, Sonoma County. Diameter breast high: 50.2 inches; yield of cork when stripped to a height of 14 feet in 1942: 650 pounds.

There are a number of fine cork oak trees in Santa Barbara, the largest of

which is reported to have been planted from an acorn brought to Santa Barbara by a man named Hinchman in 1857 and planted by Captain H. G. Trussell at 412 West Montecito Street. An article in the "News Press" stated that in 1875 this tree measured nine inches in diameter. This tree stood on an irrigated lawn, and in 1942 when over 80 years old it was 33 inches in diameter, thin in the crown and evidently suffering from some root trouble which apparently caused its death during 1945. A tree of similar size and age, but more vigorous and with thicker cork, is growing on the Sexton property in Goleta. It measured 29.17 inches d.b.h. in September, 1942.

The largest cork oak tree in California is growing near the main building of Napa State Hospital at Imola, Napa County. It is reported to have been planted in 1871, and at 73 years of age had a diameter of 58.2 inches, a height of 75 feet and a crown spread of about 100 feet. It grows on an irrigated lawn and in recent years has produced several large crops of acorns.

During the 80's there was evidently an increase in cork oak plantings, as a number of nurseries had seedlings for sale. By this time acorns grown in California were evidently produced in moderate quantity, but not many records of planting are available. The annual reports of the Agricultural Experiment Station of the University of California state that between 1886 and 1891 a total of 803 cork oak seedlings were distributed to land owners throughout the state. No record of the results of these plantings is available, but it is probable that several of the fine trees on farms in the Sacramento and San Joaquin Valleys resulted from these plantings. The well developed trees at the McGill (Doak) Ranch near Oakville, Napa County, were set out on a rocky, rolling hillside from acorns which the owner, John Benson, is reported to have sent home from Spain. The fine trees at the R. E. Fields place near Biggs, Butte County, are reported to have been planted by John Rock, President of the California Nursery Company, about 1889.

After the U. S. Forest Service was established in 1905, considerable quantities of cork oak acorns were imported and planted on the three southern forests by the seed spot method. The acorns were evidently too old and dry, for germination was very low. The few which did grow are reported to have died from drought or were destroyed by gophers. The outstanding plantation of this period was set out by the University of California in 1904 at the Chico Forestry Station in Butte County. It occupies about two acres of gravelly soil of rather poor quality, the spacing was six by six feet and the trees were cultivated for two or three years after planting, but it is believed that they were not irrigated. No thinning was done until after 1940, but undoubtedly gophers took out many of the trees during the first decade; thus the trees made slow growth because of severe competition. When 21 years of age this plantation showed 383 trees per acre; the average diameter was 5.5 inches breast high and the average height 24 feet. The largest tree was 14.6 inches d.b.h. and 39 feet tall. When stripping experiments were started in this grove in 1940, the trees were 36 years old, and 166 of them were eight inches or over in diameter breast high, averaging 11 inches d.b.h. The largest trees are at the north end of the grove where the soil is somewhat better and there is probably some subirrigation from Chico Creek. This area, now within Bidwell Park, is the natural site for valley oak, *Quercus lobata* Née, and many fine specimen trees are in the vicinity of the cork oak grove. Several rows of seed spots, using acorns from the Maher cork oak at Campo Seco, were set out on the northeast side of this grove in 1917, followed by cultivation

but no irrigation. In spite of some damage by gophers this seeding was quite successful, and a number of the resulting trees were large enough to be stripped of cork in 1943 and 1944. The largest had diameters of eight to ten inches at 26 years of age.

During the years from about 1910 to 1915 the Los Angeles County Forestry Department grew a considerable number of cork oaks each year and planted them along several county highways. The fine trees along Devonshire Boulevard in the San Fernando Valley were set out in 1915 and have developed into large and beautiful trees. With plenty of room to develop and with irrigated crops in adjacent fields supplying them some moisture, they averaged 20 inches d.b.h. and 35 to 40 feet in height when 26 years old. Other plantings of these years have grown more slowly when on poorer soil or under drier conditions, and some of them show quite severe infestation by the gall wasp insect. The fine planting of trees along the State Highway east of Davis, Yolo County, was set out about this same time and the trees have made similarly rapid and satisfactory growth with irrigated crops in adjacent fields and their roots in good Yolo sandy loam soil. Other fine rows of cork oaks along streets and highways in Riverside, Fresno, Kern, Sacramento and Placer counties show that the cork oak grows into a beautiful and satisfactory highway tree, par-

FIG. 2. Using the convex saw to make the vertical cut through the 58-inch cork oak at Napa State Hospital, July 27, 1943. Yield of cork when stripped to a height of 17 feet: 1,050 pounds. The tree is forming a good growth of new cork since the stripping.

ticularly where it receives some water from adjacent irrigated crops. It must, however, be pruned at intervals during the first 20 years in order to induce development of a clean straight trunk to a height of 10 to 12 feet.

From about 1890 on, it appears that commercial nurseries in California grew and sold cork oak trees in considerable quantities. They are listed in many catalogs, and Mr. Theodore Payne of Los Angeles promoted their planting for a number of years, particularly in 1916 when his catalog carried a fine illustration and description of a cork oak on the back cover. During these years also Mr. Emery Smith of San Francisco was a consistent advocate of cork oak planting in California. He included a display of cork stripped from trees at the James Lick property at Agnew among the exhibits of California products at the Chicago World's Fair, and though his main interest was along engineering lines, he never ceased to enthusiastically promote the planting of these trees.

The State Division of Forestry Nursery at Davis has long been a factor in the growing and planting of cork oaks, particularly on school grounds, along highways and on the grounds of state and county institutions. The records from 1930 to 1940 show a distribution of 74 lots of cork oaks in gallon cans during this period—a total of 2,864 trees before the start of the cooperative project in 1940.

Collection, Storage and Shipment of Acorns

Beginning with the crop of 1940 an effort has been made to secure a large volume of acorns each year for the growing of between 20,000 and 30,000 trees annually in California and to comply with requests from southern and southwestern states in order that they might propagate and distribute cork oaks for trial planting within their borders. By setting a price of ten cents per pound, and by urging 4-H Clubs and interested individuals to cooperate in gathering the crop while in good condition, the amount available has increased from less than 1,000 pounds in 1940 to approximately 16,000 pounds in 1945. Last year we had requests totalling 20,000 pounds for the crop of 1946. It seems fairly certain that with new trees continually reaching acorn-bearing age—about 20 years—sufficient acorns should be available in California to supply all reasonable demands for planting stock within the United States. It has been determined that fresh acorns of cork oak will average 70 to the pound and that a germinative per cent of about 90 is a normal figure. Thus with a very liberal allowance for losses in transplanting and handling it is possible to obtain at least 100,000 seedlings per ton of acorns.

It is possible to find a few flowers on cork oak trees during any month in the year, but the main blooming period in California is from about April first to the middle of May. The acorns apparently require six or seven months to ripen, and fall from the trees in largest volume from about November 15 to the end of December. The flowers are evidently self-pollinated in many cases, as trees in isolated places often produce good crops of acorns. However, the largest amounts of acorns have been consistently obtained from the plantation at Chico and from street and highway trees in Fresno and Los Angeles counties. It is believed that wind movement induced by passing automobile traffic may be a factor in good pollination and set of acorns on trees adjacent to highways. A great many trees apparently drop most of their acorns when these are very small, and some trees may be self-sterile, as they are said never to have produced any good acorns. However, birds and squirrels must be considered in this matter, as in the grove of fine trees at Kearney Park,

FIG. 3. Removing a ring of cork from a cork oak in Southside Park, Sacramento. Diameter breast high: before stripping, 26.7 inches; after stripping, 24.7 inches; length stripped: 8.5 feet; yield of cork in two cylinders: 78 pounds. The tree is said to have been planted about 1911, but seems to be about 40 years old.

Fresno County, where the pea fowl seem to consume all the acorns before they can ripen.

In order to retain their germinative capacity cork oak acorns must not be allowed to dry out. They usually fail to

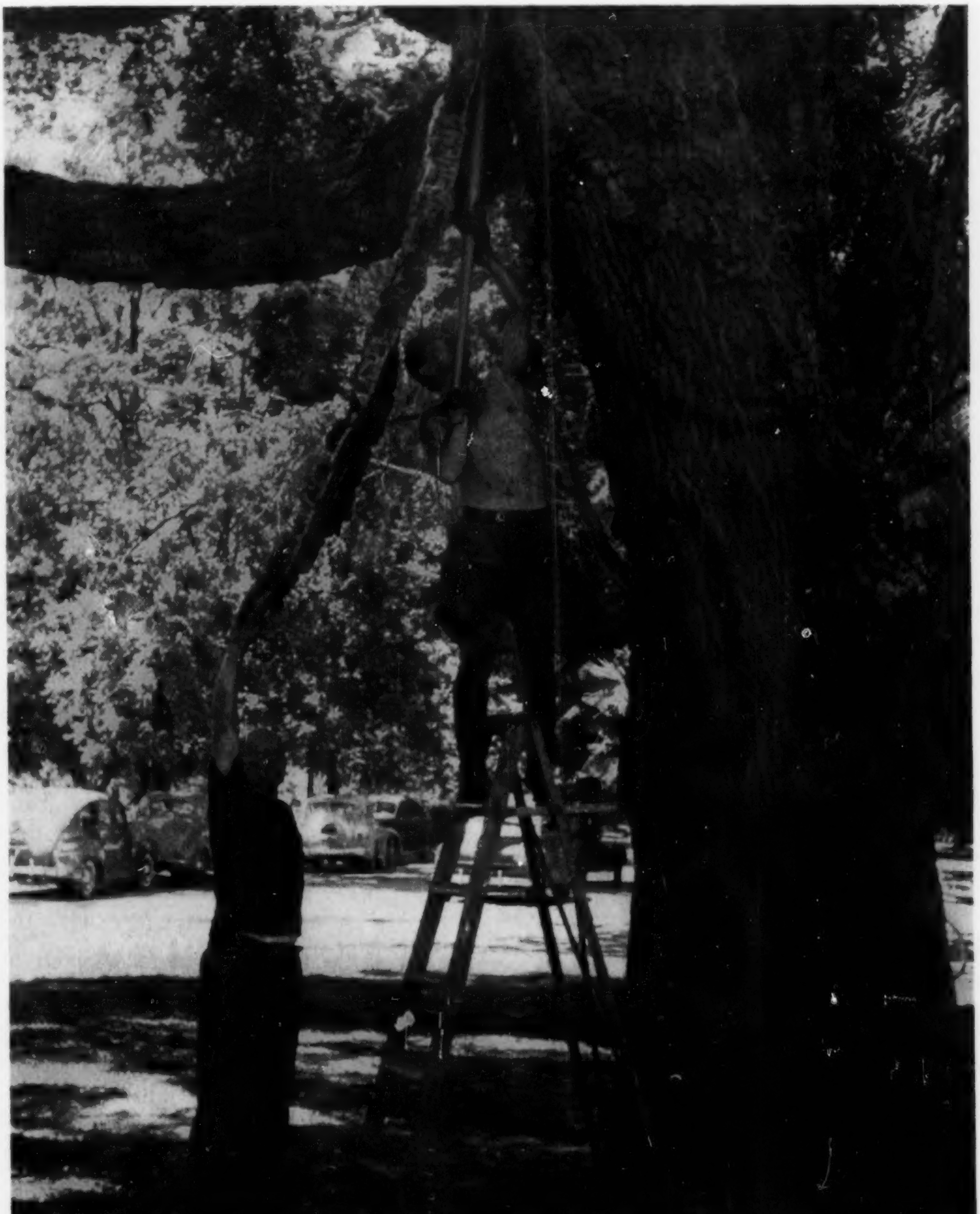


FIG. 4. The heavy peavy bar shod with metal is the most useful tool in stripping old trees with heavy bark. Using this it was possible to remove strips up to 10 feet long from the big tree at Napa State Hospital, July 27, 1943.

germinate if kept for a week or ten days in a heated building at ordinary room temperatures. However, they keep all right for several weeks if collected soon after they fall and placed in sacks out of doors in the shade, particularly if the

sacks are sprinkled with water occasionally. If left too long, however, the layer of acorns next to the ground germinates, and the roots break off when the sack is moved. Sacks of freshly collected acorns have been shipped across the country by truck and by railway express with little loss of vitality, but if too long delayed or if exposed to heat, they either germinate or ferment in transit. In either case there will be considerable loss. Dr. N. Mirov of the California Forest and Range Experiment Station has been conducting storage experiments with these acorns since 1941 and has determined that when placed in moist sawdust in tight containers at 38 degrees F. they will retain a high degree of viability for periods up to 22 months and produce vigorous and rapidly growing seedlings. Thus it will be possible in the future to hold acorns from a good crop for growing the following year in case of a crop failure; or they can be shipped under such refrigeration in excellent condition to any part of the world. In most cases, however, if handled expeditiously and kept out of doors, such refrigeration will not be necessary, except for long ocean shipments.

Nursery Practice in Growing Cork Oak

It might seem that the ideal method of growing cork oaks would be to plant acorns directly in place and protect and care for the trees until they are established. But in practice the losses from rodents, competing vegetation and drought have been so severe that direct seeding has rarely been successful. A very few natural seedlings can be found near old trees in some favorable spots. These are generally on good soil, with more than usual moisture available, and in the shade. The last is apparently a very important requirement, so that a lath house must be available for successful nursery propagation. The main problem has been to produce a sturdy seedling in a container which is not too heavy yet which is large enough to permit development of a root system which is not too severely deformed or restricted.

The number ten or one-gallon tin can with holes punched in the bottom has been the container used in propagating some 200,000 cork oak seedlings at the State Nursery. Twelve-inch tar paper pots with a two and one-half- to three-inch diameter have been used by the Soil Conservation Service nurseries and the Institute of Forest Genetics. No survival figures are available, but it seems that the cans have been somewhat more satisfactory, as they contain a larger volume of soil for root development.

When sacks of acorns are received at the State Nursery in December they are left out of doors until the sand beds are ready. Then within a week or two the acorns are spread out in a long bed, four feet in width, and covered with about two inches of light sand. Here in about five or six weeks they germinate, the tap root making rapid growth downward, the shoot developing much more slowly. The cans having been previously filled with sandy loam soil, the trees are dug from the bed during March and April, the roots are pruned to a length of about four inches and the little tree with the attached acorn is planted in the can by means of a dibble. The cans remain in the lath house until the following winter when the trees are large enough for field planting. They are watered by overhead sprinklers at about weekly intervals during the dry season and any side branches are pruned off to give the tree an erect and whiplike form with a height of eight to twelve inches. Pruning of the root induces a branching and somewhat more fibrous root system than is developed without pruning. The tree and container weigh about eight pounds.

The tar paper pots, which are often about half filled with sphagnum moss, weigh about half as much as the cans, so

are easier to transport. However, their smaller diameter results in a more poorly developed root system in most cases. Also these tar paper containers must be very carefully handled during shipment, particularly when the soil is wet.

Field Planting

During the past six years about 200,000 seedling cork oaks have been distributed to applicants through the cooperation of State Rangers, Farm Advisors, Soil Conservation Service personnel, County Foresters and so forth, and have been planted by hundreds of land owners. Survival has varied with local conditions of soil, planting technique, irrigation and care, but is believed to average about 50%.

One plantation was set out in the spring of 1940 on dredged and relevelled land at Garden Ranch near Oroville, Butte County. The trees were planted from cans on this very unpromising rocky flat, were shaded by small burlap screens and given but one irrigation during the first dry season. When recently examined there were 25% of the original 200 trees still alive. Some were three feet or less in height, but one had reached nine feet and was still making excellent growth. Another planting of 50 trees of the same stock, set out on much better land the same spring, was all destroyed by gophers before the third year.

Some experiments have been made in the use of bare-rooted stock for field planting. It is apparently feasible if the conditions at the planting site are optimum, the trees not too large, and if the move does not involve shipment for a long distance. The best results have been reported by 4-H Club members who obtained trees from a nursery row in Victory Park, Stockton, took them home and planted them the same day. If shipping distances are very long or conditions at the planting site not good, the use of bare-root stock is questionable. The cost of shipping heavy containers of soil is a major problem in the widespread distribution of seedling trees. Thus if some way can be worked out to secure good survival with bare-rooted stock, it will very greatly advance the program.

Stripping of Cork

Experimental stripping of cork oaks was begun by the writer, George D. Greenan, R. S. Waltz, and Farm Advisor, Henry Everett, on July 13, 1940, at the Chico Forestry Station grove in which the trees were 36 years old, and those over eight inches averaged eleven inches diameter outside bark. The largest tree measured 22.5 inches at breast height before stripping. Mr. Greenan had secured a heavy steel cork stripping axe from Portugal which had a curved blade and a handle tapered at the end for use as a pry bar. Two standard pruning saws, hickory pry bars made from double bitted axe handles, a couple of automobile spring leaves and a heavy hammer made up the rest of the tools. We had to start from scratch, as no one could be found who had ever watched the operation in Europe, and the written material available gave very little information on the actual procedure of stripping trees in Spain and Portugal.

The standard pruning saws proved to be satisfactory for making horizontal cuts through the cork, but we found the Portuguese axe quite unwieldy and difficult to use in making the vertical cut without undue injury to the inner bark. During the first afternoon we removed the cork from ten trees to a height of about six feet with less injury to the inner bark as we became more skillful in handling the tools. We soon determined that it was inadvisable to strip trees less than eight inches d.b.h., as the cork is generally quite thin and difficult to remove. From the larger trees the thicker cork separates quite easily at this time of year along the moist cork cambium

layer with a characteristic cracking sound when submitted to pressure from the pry-bars, and with virtually no injury to the inner bark. After the experience of the first day we presented the problem of the vertical cut to Mr. Fanno, saw manufacturer of Chico. He shortly made up a special saw with teeth on the outside of a curved blade. This proved to be ideal for the purpose and we have used it on all trees stripped during the past six years. The sharpened axe handles and steel spring leaves proved to be excellent pry bars for small to moderate sized trees, and we have continued to use them with good success. For large trees with heavy bark we have since developed a heavy pry bar from a standard peavey handle with the toe tapered to a blunt edge and shod with light metal. These two tools have greatly facilitated the work and have made it possible to strip most trees with very little damage to the tender inner bark layer.

The work of stripping at Chico grove was continued until a total of 166 trees had been stripped to an average height of 5.5 feet. In the removal of cork the breast high diameter was reduced from an average of 11 inches to 8.9 inches, indicating that the cork averaged 1.05 inches in thickness. The average yield of cork was 22.8 pounds per tree for a total of 3,783 pounds for the grove. All of this cork was treated by boiling in two changes of water in open metal tanks set up in the grove, in accordance with what is said to be established practice in Europe. It was then baled and shipped with the cork stripped from other trees that year to Baltimore, Maryland, where it was given extensive tests in the laboratories of the Crown Cork and Seal Company. From these tests it appeared that there was no significant difference between cork given this treatment in boiling water and that shipped without such treatment. Therefore, all cork stripped in the succeeding years has been shipped without boiling.

During August and September, 1940, the test stripping was continued on 60 trees at the McGill Ranch near Oakville, Napa County, 15 trees along the State Highway east of Davis, Yolo County, and seven isolated trees growing in Alameda, Sonoma and Santa Clara countries. All of these last trees had much more room to develop than those in the crowded stand at Chico, and those in Yolo, Alameda, Sonoma and Santa Clara counties were growing on soils of very good

TABLE I

SUMMARY OF CORK STRIPPING—1940

	Chico Station	McGill Ranch	Highway at Davis	Misc.	All trees
Number of trees	166	60	15	7	248
Av. diam. outside bark at 4½′ above ground	11.0″	15.6″	17.7″	23.0″	12.7″
Av. diam. at 4½′ after stripping	8.9″	12.2″	14.8″	19.6″	10.2″
Av. thickness of cork	1.05″	1.7″	1.45″	1.7″	1.25″
Av. length of bole stripped	5.5′	6.6′	8.3′	6.9′	6.0′
Total yield of cork in pounds	3,783	4,999	1,053	725	10,561
Age of trees—years	36	62	25		
Av. yield of cork per tree in lbs. per year	0.63	1.37	2.81		

The largest yield of cork was secured from a 27-inch tree at McGill Ranch, which was stripped to a height of 13 feet. The cork weighed 501 pounds, which indicates an average annual growth of 8.8 pounds for each of its 62 years.

quality. The McGill Ranch trees are widely spaced, but are growing on rolling foothill lands of moderate quality and in association with coast live oak, black oak and other native trees. They have had virtually no care since they were planted in 1878, and are thus about the best demonstration of what may be expected from trees planted on foothill sections of farm lands in the central coast country. A summary of results from these stripping experiments is given in Table I.

During the summer of 1941 test stripping of 24 trees was carried out in the San Fernando Valley section of Los Angeles County in cooperation with the Los Angeles County Forestry Department and City Forester, Fred Roewekamp, of Los Angeles. The trees, now within the city limits of Los Angeles, were planted along Devonshire Boulevard between Chatsworth and Zelzah by the Los Angeles County Forestry Department in 1915. In all, there are about 140 trees which have made very good growth and, are nice ornamental specimens. The trees had an average diameter breast high outside bark of 20.3 inches, were stripped to an average height of eight feet and yielded approximately 50 pounds of cork per tree. Most of the trees stripped very easily with virtually no damage to the inner bark. Most of the cork was firm in texture and evidently of as good quality as that procured in the northern part of the state the preceding year. Three isolated trees were also stripped during this season, including the large tree on the Maher property at Campo Seco in Calaveras County, from which some cork had been removed about 1911. The yield of cork from this tree was approximately 350 pounds when stripped to a height of 14 feet. A total of 1,611 pounds of cork from 27 trees was again shipped to Baltimore for testing as to quality.

In spite of war conditions it was possible to carry on some cork stripping of

TABLE II

SUMMARY OF CORK STRIPPING—1942

Location of tree	Age	Diam. at B.H.			Length stripped	Weight of cork
		Before	After			
Deigaard Pl. Duarte in Los Angeles Co.	30 yr.	21.0″	17.0″		10.0 ft.	85.0 lbs.
" #52	30 yr.	18.0″	13.7″		10.0 ft.	93.0 lbs.
" #54	30 yr.	22.7″	15.0″		5.0 ft.	62.5 lbs.
" #56	30 yr.	13.0″	11.1″		3.7 ft.	19.0 lbs.
Library Park, Monrovia	30 yr.?	18.5″	13.7″		8.0 ft.	107.0 lbs.
Monrovia Nursery	80 yr.?	32.0″	27.2″		8.8 ft.	181.0 lbs.
Mrs. Wales, Charter Oak	42 yr.	32.0″	25.7″		9.0 ft.	211.5 lbs.
Corona del Mar, Goleta Santa Barbara County	25 yr.?	21.1″	17.1″		9.6 ft.	87.0 lbs.
Sexton Ranch, Goleta	70 yr.?	29.7″	25.9″		5.0 ft.	121.0 lbs.
1640 Grand Ave. S.B.	30 yr.?	13.0″	11.0″		5.2 ft.	16.0 lbs.
Orella St., S.B. 2505	25 yr.?	9.5″	8.5″		5.0 ft.	10.0 lbs.
" Cor. of Almar	25 yr.?	11.3″	9.5″		5.6 ft.	15.5 lbs.
" at #2525	25 yr.?	10.5″	9.0″		7.2 ft.	20.5 lbs.
Montecito St. #321–A	25 yr.?	17.2″	14.0″		5.7 ft.	61.0 lbs.
" #325–A	25 yr.?	11.9″	9.0″	forked		
		9.8″	7.0″	at 2′	6.0 ft.	46.5 lbs.
Bagg Tree, 412 W. Montecito St. Santa Barbara	85 yr.?	33.2″	29.7″		5.0 ft.	61.0 lbs.

trees during September, 1942, in order to get samples of cork from different locations and to put these trees in condition to produce second growth cork. Data on these operations is given in Table II.

Of the trees listed in Table II the Deigaard tree #56 was very difficult to strip, the cork coming off in small pieces. This was true also of the upper ring from the tree at Monrovia Nursery. This tree seemed to be very dry because of the presence of nursery stock in cans under it which took most of the water. The fine old Sexton tree at Goleta had thin but very tough and resilient cork, but was quite difficult to strip, and the cork came off in small pieces. About the same can be said of the Bagg tree in Santa Barbara which stands on a lawn. Its cork is thin and came off with difficulty, though the tree seems to get sufficient water. Its crown is thin and it may be troubled by some root disease. The small tree at 1640 Grand Avenue was on a dry hillside with virtually no irrigation, and its cork was hard to strip. We had an impression that the season for stripping might be too far advanced for some of these trees, although others stripped with the greatest ease. The total yield from the 16 trees in Los Angeles and Santa Barbara Counties was 1,197.5 pounds of cork—an average of 75 pounds per tree.

On September 10 we moved operations to the San Joaquin Valley, working first on three of the ten trees in Central Park, Bakersfield. These are about 15 years old, are planted in rather a close grove with some coast live oaks and are watered by rotating sprinklers which keep the lower portions of the trunks wet. The cork was soft on all of the trees and quite badly rotted on the third one. The following day we worked on the large and symmetrical tree on the J. R. Morrow Ranch on Grenville Street, Porterville, Tulare County. This tree is about 75 years old and resembles a fine old American elm in its habit of growth. The cork was thick, springy and of excellent texture, but was somewhat difficult to remove because of its depth and irregularities in the inner layers. Later in the month we stripped three of the twelve young cork oaks at Victory Park, Stockton, with the assistance of Park Superintendent Victor Anderson who stated that the trees were not more than 15 years old. A summary of these operations is given in Table III.

During September, 1942, we also worked on the finest group of old trees in California, with the assistance of Palmer Stockwell and the owner, J. T. Kiser. These trees are said to have been planted along an old road near Sonoma Creek sometime between 1850 and 1860, so are probably the oldest cork oaks in the state. It is reported that 25 or more trees were planted at that time, but that all but these four were badly damaged by grazing animals. The old trees have beautifully dense and rounded crowns and are said to have produced good crops of acorns at intervals for many years. Some patches of cork had been removed by curio seekers for many years, and George Greenan stripped a five foot ring from tree #3 in 1940 which weighed 60 pounds. The other trees and several small ones were stripped September 18, 19 and 20. The cork cambium layer was moist and apparently active at this date, and the cork was removed quite easily except from pressure areas in the crotches and at points on the branches 12 or more feet above the ground. The Kiser Ranch is 2½ miles south of the town of Sonoma in Sonoma County. The trees show moderate infestation from gall wasps which have not seriously damaged them. There is some natural reproduction near them. The results are summarized in Table IV.

Mr. Kiser is of the opinion that some of the smaller trees are sprouts from the old stumps which have survived damage

TABLE III

CORK STRIPPING IN THE SAN JOAQUIN VALLEY—1942

Location of tree	Age	Diam. at B.H.		Length stripped	Weight of cork
		Before	After		
Central Park, Bakersfield	15 yr.?	11.5″	9.4″	5.0 ft.	32.0 lbs.
" " "	15 yr.?	13.5″	11.3″	6.4 ft.	38.0 lbs.
" " "	15 yr.?	12.4″	9.9″	6.5 ft.	44.0 lbs.
Morrow Ranch, Porterville	75 yr.?	42.2″	37.5″	6.0 ft.	204.5 lbs.
Victory Park, Stockton	15 yr.	17.5″	15.0″	6.2 ft.	24.0 lbs.
" " "	15 yr.	15.2″	13.0″	9.0 ft.	35.0 lbs.
" " "	15 yr.	16.0″	13.5″	10.0 ft.	60.0 lbs.

by cattle and finally reached tree size. Assuming that the trees are 85 years old, tree #4 has produced cork at the rate of ten pounds per year, and trees #1 and #2 better than 6.5 pounds per year. The yield of virtually a ton of cork from these three trees indicates that old ornamental cork oaks may be quite a factor in cork production, even without systematic stripping to improve the quality of the cork. It is agreed by most owners and observers that stripping does not impair the ornamental value of the trees, but rather adds to their interest. The smooth pinkish-tan inner bark gradually changes color during six to eight months after stripping, becoming dark red, then brown, then almost black with cracks through which the rapidly forming new cork shows as tan-colored vertical streaks.

The most interesting event of the 1943 cork stripping season occurred on July 27th when through the kind cooperation of Superintendent Mason of Napa State Hospital we were permitted to remove the cork from the largest cork oak in the United States. The tree stands on an irrigated lawn on the north side of the main building and is said to have been planted in 1870 or 1871. Its diameter breast high, measured 58.2 inches before stripping, which was reduced by stripping to 53.5 inches, indicating that the thickness of cork was 2½ inches at this

TABLE IV

STRIPPING OF CORK OAKS, KISER RANCH, SONOMA COUNTY, SEPTEMBER 1942

Tree number	Diameter		Length stripped	Weight of cork
	Before	After		
1	50.2″	48.8″	14.4 ft.	576 lbs?
2	gr. 50.0″	45.0″	8.0 to 11.0 ft.	551.0 lbs.
3			5.0 ft. (1940)	60.0 lbs.
4	gr. 54.0″	49.0″	9.0 to 10.0 ft.	851.0 lbs.
	Note: Trees #2 and #4 fork near the ground so that diameter was measured just above the ground. After stripping the breast high diameters of the branches were on #2—27.5″, 26.0″, and 20.2″; on #4—34.0″, and 25.5″.			
A	11.7″	9.5″	6.3 ft.	39.0 lbs.
B	10.5″	8.5″	3.7 ft.	10.0 lbs.
C	12.0″ 10.0″	9.0″ 7.7″ forked at 3′	4.5 ft.	38.0 lbs.
D	7.8″	6.8″	6.0 ft. Nat. seedling	14.5 lbs.

point. The cork came off this tree very easily and the cork cambium was so moist at several points on the trunk that water dripped from the sheets of cork as they were removed. The heavy peavey bar was most effective in working on this tree, and in one case we were able to remove a strip of cork ten feet in length without breaking it. All of the cork on the tree was removed to a height of 17 feet above the ground with the exception of that on one horizontal branch. When removed from the base of the tree on July 31, it made a full load for the Pontiac station wagon and weighed 1,050 pounds. Thus this fine tree in its 73 years had been producing cork at an annual rate of 14 pounds for its entire lifetime. The tree showed no set-back as a result of the stripping, the few cuts through the inner bark healed quickly and the new growth of cork is coming along in a vigorous and satisfactory manner.

Three trees about 15 years old, grown from acorns from the big tree, stand beside the ranch road in front of the dairy building on the Napa State Hospital grounds. These trees are somewhat larger and have evidently had somewhat better irrigation than others in the same row. They were stripped July 23, 1943 with the following results:

Tree	Diameter		Length stripped	Weight of cork
	Before	After		
West	12.0″	10.4″	7.7 ft.	40.0 lbs.
Middle	8.6″	7.5″	7.2 ft.	21.7 lbs.
East	11.8″	9.7″	7.1 ft.	27.5 lbs.

Among other interesting trees stripped during the 1943 season were two 50-year-old trees at Kearney Park in Fresno County. The first of these was a fine specimen with two low horizontal branches below which the diameter measured 44.2 inches, the main trunk being 30.6 inches d.b.h. The two branches were so low that they could easily be worked from the ground. The larger one stripped for 15 feet from the trunk was reduced in diameter from 22.2 inches to 19.8 inches; the smaller one stripped to a length of 6.8 feet was reduced from 17.8 inches to 16.3 inches. The d.b.h. of the main stem was 27.7 inches after stripping. The yield of cork was 315 pounds. The second tree measured 20.2 inches d.b.h. outside bark and had a straight clean bole to a height of 15 feet. This tree stripped so easily that we removed a cylinder of cork ten feet long in a single piece which weighed 92 pounds. The diameter breast high measured 16.2 inches after stripping, showing the cork to be two inches in thickness. Besides the 50-year-old trees at Kearney Park there is the fine "mound" grove of a dozen or more trees planted in 1913. All the trees here are flood-irrigated twice during each dry season. They all show some attack by gall wasp, but seem not to be badly affected by this insect. Other trees worked on were in Alameda, Merced, Madera, Fresno, Tulare and Kern Counties. Most of them stripped easily with the exception of one at Jasmine which was the most difficult of any tree we have worked on. The cork had to be forced off in small pieces but was of good quality. Another very difficult tree to strip was a small specimen at Fiddletown in Amador County which yielded only 44 pounds of cork in small pieces. The big tree there which we stripped on September 3 had firm cork of excellent quality which stripped very easily and yielded approximately 250 pounds from 8.5 feet of stem. The breast high diameter was 36.5 inches before and 30.3 inches after stripping. The old inhabitants of this mining town seem to think that this tree was planted about 1856. It has produced very good crops of acorns. This same week we stripped the fine old tree at the deserted mining town of Todd's Valley in Placer County

at 2,700 feet elevation, which puts it in the lower portion of the ponderosa pine belt. The tree was probably planted in the yard of a nice residence about 1860 in a place not disturbed by the old drift and hydraulic mining operation. The property is now owned by Mr. T. de-Roode of New York who went with us to see the operation. Cork was removed to a height of 7.2 feet for a yield of 185 pounds. Some of the ridges of cork were six inches in thickness and the cork was of excellent quality. Diameters breast high were 38.3 inches before and 33.4 inches after stripping. Only two or three buildings are now standing in the area which between 1850 and 1861 is said to have had a population of 12,000. The old mining areas near the tree are coming up to a fine stand of young ponderosa pine.

On September 29, 1943, we stripped ten small trees at Chico Station grove in order to test the effect of paint and other coatings of the inner bark applied within one hour of the time of stripping. The trees stripped just as easily on this date as they had earlier in the year. The coatings used were *a*) tan colored porch and deck paint; *b*) blue flat wall paint; *c*) "Opex" colorless lacquer; *d*) thick sodium silicate solution; *e*) cream colored kalsomine; *f*) heavy builder's paper tied with twine. Later examinations seem to indicate that the tree wrapped with paper made the best recovery and most rapid growth of cork. The tree coated with the colorless lacquer died. The other applications seemed to have little effect on the development of new cork on the stripped portion of the trunk.

During the 1944 season trees were stripped in Alameda, Merced, Fresno, Kern, Los Angeles and Ventura counties with about the same results as indicated above. The following may be mentioned as most interesting: One of the 31-year-old "Mound" trees at Kearney Park, Fresno County, measured 31.4 inches below the fork outside bark before stripping and 28.6 inches afterwards. Ten feet of stem yielded 165 pounds of cork which came off very easily. The cork oak on the lawn of C. H. Powers, 230 Citrus Avenue, Azusa, is 54 years old, 65 feet tall with a clear length of over 20 feet and is one of the most beautiful cork oaks in Los Angeles County. It was stripped to a height of 10.5 feet on August 18, the excellent quality cork easily coming off in two perfect cylinders. Stripping reduced the d.b.h. from 35 inches to 29.2 inches, and the yield of cork was 235 pounds. The finest cork oak in Ventura County stands in a citrus grove on the property of R. H. Peyton near the Rancho Sespe at Fillmore. It is approximately 60 years old and is said to have been given as a premium by the San Francisco Call Bulletin. The tree has always received good irrigation and cultivation and has had plenty of room to develop, as it towers above the orange trees. It measured 40 inches d.b.h., 50 feet tall with a clear length of ten feet, and a crown diameter of 60 feet. We stripped 5.3 feet of stem leaving the d.b.h., after stripping, 35 inches, showing that the cork was 2½ inches in thickness. The cork stripped easily though not in one piece and seemed to be of excellent quality. The yield was 200 pounds. The tree is a beautiful ornamental specimen, is in excellent condition and shows little evidence of attack by gall wasps or other enemies. This appears to confirm the opinion that gall wasp attacks are apt to be most serious on those trees which are growing on poor soil or suffering from a deficiency of moisture.

During the 1945 and 1946 seasons stripping of trees was confined to a series of method demonstrations arranged by Farm Advisors in different counties for the benefit of those who had planted trees and were interested in methods of harvesting cork.

Regrowth of Cork After Stripping

At the time of stripping the cork cambium is in active growth and quite moist. It soon dries to a depth of about one-eighth of an inch into the sheath of inner bark remaining on the tree, and during a period of months it goes through the series of color changes from pinkish-tan to dark brown. The new growth of cork starts from re-established cork cambium below this dried "hardback" layer exposed to the air. The recuperative powers of this inner bark layer are quite remarkable, and production of new cork is so rapid that within a few months the bright tan color of the fresh cork can be seen through vertical cracks in the dry outer layers. By the act of stripping, the tree appears to be stimulated into great activity for the rapid replacement of the protective layers of cork. Also the healing of wounds, which may have been made through the inner bark to the cambium layer, is very rapid on all trees in vigorous condition. After losing about half of its thickness from the drying, the inner bark layer evidently remains thinner than it was for a number of years, all energy appearing to go into the formation of cork. In order to test the vigor of this inner bark layer, tree number 6 at Chico was stripped a second time in 1943 with complete removal of the second-growth cork to the same height as in 1940. This tree yielded 13 pounds of cork at the original stripping and measured 7.4 inches d.b.h. after the cork was removed to a height of 6.2 feet. In 1943 it measured 8.9 inches before stripping and 7.9 inches after removal of the ring of second-growth cork which weighed 14 pounds—one pound more than had been originally taken from the same trunk area three years before. Later examinations of this tree indicate that it is still in vigorous condition and putting on a third growth of cork.

It has now been possible to remeasure a considerable number of trees in order to give an idea of their recovery after stripping and the development of "second-growth" cork during a five-year period. Results which are summarized in Table V show such rapid growth that the diameter outside bark before stripping has generally been regained and often exceeded at the time of the second measurement.

One of the Davis trees (5-S), which measured 16.5 inches in diameter before and 14.2 inches after stripping in 1940, was restripped in September, 1945, when its diameter had reached 21.5 inches. By removal of about 100 pounds of second growth cork, the diameter was reduced to 18.6 inches at breast height, which indicated a growth of about four inches in diameter for the wood cylinder of this tree in five years. This is in marked contrast to the much slower growth of the crowded trees on poorer soil at Chico. On July 7, 1946, a cylinder of cork 4.3 feet long was removed from tree 3-N in this highway planting, the yield of cork being 59 pounds. Its diameter had been reduced from 19.1 inches to 16.7 inches by stripping in 1940. It had grown to a d.b.h. of 26.2 inches in the six years

TABLE V

REGROWTH OF CORK IN FIVE YEARS AFTER STRIPPING

Location	Number of trees	Average D.B.H. Before	Average D.B.H. After	5 years later
Chico, Butte County	148	(1940) 11.03″	9.05″	(1945) 10.7″
Davis, Yolo County	13	(1940) 17.2″	14.4″	(1945) 22.2″
Chatsworth, Los Angeles County	13	(1941) 22.7″	20.4″	(1946) 23.8″

which was again reduced to 23.2 inches at a point just below the upper edge of stripping. The cork, therefore, had grown to a thickness of 1.5 inches in the six years since stripping and seemed to be of very good quality, being at the rate of about 18 pounds per year for this tree which is now 58 feet tall at 31 years of age. Very similar yield of cork was indicated from the Chatsworth trees growing on similarly good soil when 53.5 pounds of very good cork were removed from four feet of stem of tree (N-2) August 6, 1946. Its diameter before stripping in 1941 had been 23.0 inches with recovery to 22.9 inches in the five years. After the second removal of cork it measured 20.4 inches diameter at the top of the stripped portion. The cork again seemed firm and of very good quality.

In order to obtain a comparison of growth on unstripped trees, 13 of the Chatsworth trees were selected which had virtually the same diameters in 1941 as the 13 stripped trees. Average d.b.h. was 22.9 inches in 1941 as against the 22.7 inches shown in the above table. After five years the unstripped trees showed an average diameter of 25.4 inches as compared with the recovery to 23.8 inches by those from which bark was removed in 1941. Thus if the average bark diameter in 1941 (2.3 inches) be subtracted from the average diameter for 1946, we get a calculated d.b.h. of 23.1 inches for the unstripped trees, while the actual measurement of the stripped trees was 23.8 inches. Though some of this must be assigned to wood growth, it is further indication of the stimulation of cork production by stripping. Individual trees for which records are being kept indicate similar rapid growth after stripping. The Boyle tree which stands on irrigated lawn at 1337 Highway 99 in Kingsburg, Fresno County, was stripped in August, 1943, to a height of 8.75 feet when it was 13.5 inches diameter outside the cork and 11.0 inches after stripping. It was then about 18 years old and the yield of cork was 51 pounds. In August, 1946, after only three years it measured 14.8 inches d.b.h. and is making an excellent growth of cork.

During the past six years nearly 500 trees have been stripped in California with a total yield of approximately 15 tons of cork. Most of the trees have released their cork quite easily and with very little injury to the inner bark. Any damage to inner bark or cambium layers is usually healed over very quickly where trees are in vigorous condition. Only three trees have died following stripping, and it appears that these were suffering from excessive drought or were otherwise in poor condtion. Stripping has been conducted from July 1 to early October with little apparent difference in ease of stripping during the season. We feel that stripping should be confined to trees in good growing condition and with vigorous and full crowns. Such trees show very little setback as a result of cork removal.

As a result of this work, the following tentative estimates of yield are suggested as possible for cork oaks growing in California under good conditions:

TABLE VI

TENTATIVE ESTIMATE OF CORK YIELD PER TREE

Age	Yield in pounds
10 years	None
20 "	15 to 20
30 "	30 to 50
40 "	50 to 75
50 "	75 to 100
60 "	150 to 200
70 "	250 to 400
80 "	500 and up

If trees were stripped every eight to ten years beginning at about 20 years, it seems likely that the resultant stimulation may increase the estimated yield

in the above table by one and one-half to two times. It appears that the cork produced by trees on good soil and making vigorous growth is of about as good quality as that from trees on poorer soil or drier conditions. This may not hold true for higher quality cork articles, such as wine bottle corks, but the cork from fast growing trees seems to be fully suitable for composition articles and insulation blocks.

Quality of California Cork

During the last six years about 15 tons of cork have been stripped from California trees and shipped for testing to Dr. Giles B. Cooke, Research Department, Crown Cork and Seal Company, Baltimore, Maryland. He has made several grinding tests and a considerable number of composition cork articles which he says are very good. He reports as follows on one of the typical shipments:

"The total weight of the bales used was 1978 pounds, of which 239 pounds (12% of the shipping weight) was in the wrapping and baling material, leaving 1739 pounds gross weight of cork. In grinding, granular particles of three standard sizes were produced for a total of 686 pounds, or 39.44 percent of the sample. This cork is of excellent quality and can be used in the manufacture of composition cork for closure liners, gaskets, cork sheets and many other purposes. Other very small but usable particles (30 to dust) amounted to 413 pounds or 23.75 percent of the sample. This very fine material is not suitable for composition cork to seal foods and beverages, but may be used in linoleum, shoefillers and other commercial articles. Thus 63.2 percent of the material is useful in industry, leaving 36.8 percent as non-usable hardback, moisture *etc.*"

Dr. Cooke says, "The results of this work are most encouraging and I see no reason why this cork cannot be used interchangeably with the imported grade."

One lot of cork amounting to 1,692 pounds was forwarded by Dr. Cooke to the Armstrong Company and was tested in their Camden Plant to determine its suitability for producing corkboard. Mr. A. L. Jennings reports on these tests as follows:

"This material was ground and sized through the regular production equipment. The three-quarter to ten mesh material was made into corkboard in the regular steam baking molds according to standard practice.

"The slabs as received contained a high percentage of "Red dog" and the cork was very brittle. These characteristics resulted in a low yield of three-quarter to ten mesh cork. The ground cork showed a definite tendency of the particles to be rounded instead of having an irregular fracture. The particle size of the three-quarter to ten mesh cork was very uniform and contained little or no fines.

Gross weight of sample	1692 pounds at 16.45% moisture
Ground cork (3/4 to 10)	789 " " 1.1 % "
this equals	46.63% of the gross
By-products obtained:	
size 20 to dust	268 pounds
10 to 20 hardback	285 "
10 to 20 airfloat	90 "

Screen analysis of ground cork:

Retained on .525 Mesh	4.0%	Average weight 7.0 pounds per cu. ft.
" " .371 "	34.0%	
" " #3 "	42.6%	
" " #6 "	18.8%	
" " #8 "	0.6%	

"Blocks were baked from 100% of the subject cork and from mixtures containing 25, 50, and 75% of foreign cork. This domestic cork has much the same effect upon the baking of corkboard as has foreign young limb virgin cork. Data showing typical mixes and average physical properties of the baked block are as follows:

Block No.	Mixture	Bake-out Loss	Density lbs/bd/ft	Modulus of Rupture lbs/sq/in	Deflection inches
1.	100% domestic	16.9%	.631	25.9	.69
3.	100% "	20.4%	.589	28.1	.83
7.	75% " / 25% regular	18.7%	.654	28.4	.67
9.	50% domestic / 50% regular	17.7%	.641	16.1	.48
11.	25% domestic / 75% regular	17.7%	.612	22.5	.59
17.	100% domestic	17.4%	.602	26.0	.63

"From the above table it will be noted that all samples met the requirements of Federal Specification HH-C— 561b excepting board #9 which failed to meet the modulus of eighteen pounds."

It appears from these two reports that from 50% to 60% of the weight of cork samples shipped can be utilized for commercial articles of good quality.

Enemies of the Cork Oak

Young trees of cork oak are subject to severe damage by gophers, rabbits, domestic live stock and deer. It is necessary to give them protection from these animals for several years after planting. In most parts of California the seedlings must have shade and one or two irrigations during the dry season if satisfactory survival is to be expected. In most cases it is advisable to remove competition of grass, weeds and brush during the first few years.

The most serious pest is evidently the tiny gall wasp *Plagiotrechus suberi* which seems to be well distributed throughout California. Eggs are laid on soft bark of small twigs which swell as the larvae develop and later turn brown and die from the numbers of tiny emergence holes. Attacks of this insect seem to be worse on trees which are suffering from drought or poor soil. Many have become so unsightly from dead twigs and thin crowns that they have been removed. The common California oak moth will occasionally defoliate cork oaks but may be controlled by spraying. There is no known control for the gall wasp.

At least one cork oak in California is known to have died from oak-root fungus *Armillaria mellea.* This tree stood in the old Hihn residence gardens in Santa Cruz. It may be that the Bagg tree in Santa Barbara was also attacked by this fungus which is undoubtedly more apt to attack trees growing on irrigated lawns. Planting stock with deformed or damaged root system is quite susceptible to attack by this parasite. The best defense against these insect and fungus enemies is to use sturdy planting stock and give the trees good protection and care until they become well established.

Summary

Cork oaks have been planted in California since about 1855, and there are some outstandingly fine specimen trees growing from San Diego to Eureka at elevations below 2,700 feet. There are about 5,000 trees more than ten years old in the state.

Cork oak acorns produced in California average 70 per pound, have a high germinative capacity which can be maintained for twelve months or more by moist cold storage at 38° F., and during most years it should be possible to obtain from five to ten tons of cork oak acorns from California trees.

During the past six years about 200,-000 seedling trees of cork oak have been grown and distributed to land owners

under the cooperative cork oak project. Where carefully planted, protected from animal damage and given adequate irrigation, shade and care, many of these plantations have shown excellent survival and growth.

Because of the kind interest and cooperation on the part of owners of cork oak trees, it has been possible to carry on experimental stripping of about 500 cork oaks during the past six years. The stripping season has been found to be from about July 1 to early in October. Most vigorous and full-crowned trees can be stripped easily with the special tools developed and with virtually no damage to the inner bark. It is not advisable to strip trees which are thin crowned or suffering from drought, insects or disease. Removal of cork from ornamental cork oaks changes their appearance but does not seriously check their growth or lessen their ornamental character.

The 15 tons of cork has been quite thoroughly tested and found to be well suited for the making of composition cork articles, insulation blocks and other commercial articles. It is reported to be fully interchangeable with Mediterranean cork of similar character and grade.

Regrowth of cork after stripping has been rapid and satisfactory with trees, usually regaining the diameter before stripping in five years. Indications are that the reproduction cork is of excellent quality. Trees 25 to 30 years of age when stripped have put on a growth of 100 pounds of reproduction cork in five years.

The most serious insect enemy of the cork oak in California is the gall wasp which kills many twigs, particularly on trees in dry locations. There is no known control for this pest.

If the cooperative distribution of trees can be continued until there are one million cork oaks growing in California, they will when 30 years old contain an emergency supply of 50,000 tons of cork. This amount may be increased and the quality improved by successive stripping of the trees after they become 20 years of age.

Utilization Abstracts

Medicinal Plants in Britain. "Reports indicate that the valuable collections of medicinal plants made during the war are not being continued this Summer, with the possible exception of Raspberry leaves, which are being tested for their reputed usefulness to midwives. Britain is presumably reverting to the pre-war 'Mad Hatter' arrangement regarding Digitalis, of which we need four hundred tons a year. Britain grows the best and most potent Foxgloves in the world (the Welsh plants are particularly good), yet in ordinary times we do not produce our own Digitalis. We export seeds to Russia, where Foxgloves do not grow wild but are cultivated, and the Russian-produced Digitalis, made cheap by ill-paid labour and a heavy State subsidy, is then exported to Britain. The only natural advantage enjoyed by the Russians is a climate which permits the leaves to be dried without artificial heat —which was, of course, provided for the purpose in Britain during the war. The position of certain other imported drugs is only one or two degrees less preposterous. For example, the wild Autumn Crocus which yields colchicine, is so abundant in some western counties that it is (by reason of its poisonous character) a serious pest in farm pastures". (*Anon., Gardeners' Chronicle 119: 276. 1946*).

Timbers of British Honduras. "Notes on forty-two secondary hardwood timbers of British Honduras", issued in 1946 by the Forest Department of that country, describes the properties and uses of such timbers. (*A. F. A. Lamb*).

Minor Fiber Industries

In which Spanish moss, Palmetto palm, Spartina grass and Teasel bur each plays its role by contributing to the manufacture of particular commodities.

BRITTAIN B. ROBINSON*

Introduction

MANY readers are familiar with the major plant-fiber-producing industries of the United States, namely, those of cotton, broom corn, flax and hemp, but are not familiar with the fiber industries of lesser renown. It is the purpose of this article to discuss four of these so-called minor industries, namely, those utilizing Spanish moss, palmetto, Spartina grass and teasel. Among these industries it is only with respect to palmetto and Spanish moss that fibers are extracted from the plants, as is done with cotton, flax and hemp, but the utilitarian value of the others is largely dependent upon their fiber content, as is true also of broom corn, and their utilization is thus appropriately included in the category of fiber industries.

References on the subject reveal that there have been sporadic attempts in this country to produce fiber from yucca, crotalaria, jute, abutilon, milkweed, apocynum, nettle, cattail, ramie and other plants than those mentioned above. All these attempts, with the exception of those involving ramie, have not resulted in any long period of continuous production. At present, production of ramie is under way on a rather extensive scale in Florida, and it is hoped that a continuously profitable industry will result from these experimental undertakings.

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The United States is fortunate in covering a large area from the semi-tropics to the cooler temperate regions, within which one is able to find regions of different climates and soils that are capable of growing a wide variety of plants. Unfortunately the fact that many plants can be grown in the United States does not mean that an industry producing them here would be profitable. Another country may have equally favorable soil and climate, and, in addition, have the advantage of cheap labor. It is under such conditions that jute, for instance, is grown in India, whence we import large quantities of it that are consumed in greater amounts than all other plant fibers combined, with the exception of cotton. There are, however, many cordage, brush and broom fibers as well as plant fiber fillers imported into this country which are obtained from strictly tropical plants that could not possibly be grown within the continental United States, and imports of those fibers are necessary to sustain our manufacturing industries using them.

The purpose of this paper, as already stated, is to describe the Spanish moss, palmetto, Spartina grass and teasels industries. It is hoped that the discussion will lead to a better understanding of the industries in reference to their competitive fields and their future potentialities.

Spanish Moss

The material known by the names "Spanish moss", "Southern moss",

"Florida moss" and "Louisiana moss", and its commercial form "Black moss", is not a true moss, but a plant or the product of a plant belonging to the pineapple family. Its botanical name is *Tillandsia usneoides* L. It is a true epiphyte, growing on either live or dead trees, or sometimes even on telegraph and telephone wires. It is distributed from the Dismal Swamp of Virginia along the coast to Florida, and westward to Louisiana and Texas. Other species of the same genus extend southward in the Gulf region through Mexico to Central America. It grows luxuriantly in very moist localities.

The moss is collected when there is a slack in other work, and is often gathered by individuals to obtain an immediate cash return upon delivery of the harvest to a moss company. The material is pulled from trees with hooks or rakes on long poles, or it may be collected on the ground after storms which blow it down. A large part of the Louisiana output is fallen moss gathered from the bayous where it drops from the cypress trees. Sometimes it remains under water until cured. Frequently a man working in a tree will have a boy on the ground removing sticks and leaves from the moss pulled down. In dense growths of it a collector can pull down and gather, free of sticks, 100 pounds in an hour, but the average collection may be closer to 500 pounds per day.

The green moss is purchased from the collectors by moss-ginning companies which may operate a number of curing yards not located at their gins. A large number of such yards are scattered around central Florida, for the green or gray moss is not considered of sufficient value to transport great distances to the gins. After curing, the moss is trucked from the curing yard to the gin. In addition, the companies send out trucks to buy cured material from scattered collectors. The cured moss may be purchased beside the road, but no green moss is ordinarily bought by the trucks. The collector trucks his own green moss to the nearest curing yard.

In curing moss in Florida the material is placed in long piles, approximately 20 feet wide, 100 feet long and six feet deep. It is then watered, and during the watering and tramping which may occur in watering, the pile settles one to one and a half feet. Then it is not touched for six weeks, after which time it has settled to 18 to 24 inches in depth. The outer moss is still gray, but that under the surface of the pile is now brown to black. Longer curing in the beds is necessary to get a good black product. During the curing considerable heating, resulting from biological activity, occurs in the bed.

The moss after curing is placed on wire racks to dry. In some cases the beds are opened and small piles are made on the ground to facilitate drying before the mass is moved to the racks.

Various estimates are given for loss in weight during curing. For brown moss the loss may be 60% to 75% and for black moss as much as 80%. These are losses in the curing alone. Further losses occur in ginning. In ginning black moss that has lost 80% in curing, half of the remaining weight is subsequently lost so that the final yield is 10 pounds of black moss per 100 pounds of green moss. The yield is higher for brown moss, but losses may be 60% to 70% in ginning. The yield from moss collected in winter is higher than from that collected in summer. One estimate was that the summer yields are only one-half of the winter yields. This is due to new growth of the summer harvest which has little recoverable fiber.

In ginning, the cured dry moss is fed into a kind of gin consisting of fluted rollers and a toothed cylinder which may or may not work against a toothed concave surface. After passage through

the gin the moss is shaken over a wire screen or latticework floor to free the fiber of loose bark. The fiber is then sorted for color and cleanliness and baled for market.

In August, 1946, the price paid in Florida for green moss ranged from 70¢ to possibly $1.00 per 100 pounds delivered at the moss yard; the price for cured moss was $5.00 per 100 pounds. Most moss is purchased green. In 1937 green moss was bought for 25¢ per 100 pounds and cured moss for $2.50 per 100 pounds.

The Office of Price Administration had ceilings on the sale of moss during the first half of 1946, $17.75 per 100 pounds of black moss, $16.25 for brown moss. Very little black moss was produced in Florida under these prices, as the gins claimed that too much weight was lost in curing moss until it was black for the slight additional increase in ceiling price.

The refined black moss is sold by the ginning companies largely to upholsterers' supply firms which in turn sell it for use in furniture cushions. It has also been employed in the cushions of automobiles and railroad cars, being well adapted for such use because of its great resiliency. Among other plant fillers used for similar purposes are kapok, cotton linters, crin vegetal (shredded palm leaves,) sisal waste, cocoa fiber, flax tow and excelsior. Cotton linters, flax tow, Spanish moss and excelsior are of domestic industries.

The annual production of Spanish moss in Louisiana has until recently outranked that of Florida. Some estimates place the Florida amount in 1946 over 4,000,000 pounds of ginned moss. Older references have indicated an annual production of nearly 10,000,000 pounds for the United States.

Cabbage Palmetto

There are about half a dozen species of palms called "palmetto" growing in the Southern States, chiefly Florida. The most important of these as a fiber plant is *Sabal palmetto* (Walt.) Lodd. It is commonly known as "cabbage palmetto", but also is called "Carolina palmetto". It is native to Florida and the region northward along the coast to North Carolina. In Florida it is distributed all over the State except the extreme northwestern portion. It is normally an erect tree attaining a maximum height of 80 feet with a trunk diameter of two feet or less. The trunk is clothed during early life with old "boots" remaining from decayed leaf-stalks. As the tree grows older these fall away, leaving a fairly smooth, slightly ridged stem. The leaves are fan-shaped and shiny, reaching a maximum length of about five feet and a somewhat greater breadth. The slender unarmed petioles attain a length of seven feet. The dark colored or black fruits average about one-third inch in diameter. The cabbage palmetto is found growing in marshes, hammocks and sandy soils, and because of its adaptability to various soils it can be grown as an ornamental throughout most sections of the southeastern coastal section. It is not damaged by cold in Florida.

The palmetto produces a valuable fiber from the "boots" surrounding the terminal bud or cabbage. Recovery of this fiber for use in brushes has been a Florida industry for more than 50 years. In 1897 Charles Richards Dodge, in U. S. Department of Agriculture Fiber Investigation Report No. 9, described the preparation of this fiber by a factory located in Jacksonville, Florida. At present there are at least four mills in Florida engaged in this work. These mills have been estimated to produce 500,000 to 1,000,000 pounds of cleaned, prepared fiber annually. Further, it has been estimated that with more systematic management of harvesting it would be possible to increase the production from two to three times the present production, and some estimates are even ten

times the present production before reducing the supply of productive trees. However, due to lack of systematic management, the economic productive areas have probably tended to decrease in recent years. When it is realized that each bud yields only one and a half to three pounds of fiber, possibly averaging about two pounds, it will be understood that at present some 250,000 to 500,000 trees are used annually by this industry.

The palmetto fiber is in the "boots", or spathes of the leaf stems, which surround the "bud", or "cabbage", and in securing the bud surrounded with the upper leaf boot stems, the tree is sacrificed. The buds, usually three to four feet long and about ten inches in diameter, are cut out of trees in large groves and are trucked or shipped to the mills for processing. They average about 50 pounds in weight, but may weigh as much as 100 pounds, and contain a very high percentage of water when harvested. Buds of the above size are preferably obtained from trees six to eight years old. Although their removal results in the death of the trees, a grove of palmettos may be systematically harvested every three to five years, since removal of the larger trees gives more sunlight and nourishment to the small trees in the undergrowth, resulting in an area becoming even more productive after the first and second cutting than at the time of original cutting. Buds are not harvested from many old groves where the palms are very tall. If the palm trunk is taller than ten feet it is considered uneconomical to harvest it, for a tall tree necessitates a cutting to fell it and another cutting to remove the top three or four feet containing the bud.

The buds should be delivered and processed before becoming too dry which results in oxidation and deterioration. In summer during warm weather the buds may be kept only about ten days, but in winter about 30 days of storage is possible without too much drying.

The buds upon arrival at the mill are placed in large cement tanks and boiled for two or three days. The cooking softens and loosens the mass of boots surrounding the bud, permitting them to separate from one another when removed from the tanks and crushed between rollers. The desirable fiber is mainly on the outside of the boot; the inside has a cross net of fiber that is removed. The pulp and undesirable fiber is removed by holding the crushed boots against a revolving drum which is covered with hackle pins that shred and comb away the waste from the marketable fiber. The fiber is then dried, oiled, sorted, trimmed to desired lengths and packaged.

The fibers are from 9 to 42 inches in length, but mainly about 24 inches. Fiber at the butts of the boots is coarser than at the tips. Further, plants growing in swamps have possibly coarser fiber than those growing on higher dry ground. Yellowish brown is considered the best color, although much fiber may be a deep brown. Yields of fiber vary, depending somewhat on the water content, a moist bud containing about 5% dry fiber.

The fiber is largely used for brushes in breweries, creameries, citrus factories, *etc.*, where it is desired because it remains stiff in hot water and caustics and does not soften and become a mop, as occurs with some brush fibers. Its chief competitor in this field is Palmyra, a brush fiber imported into the United States from India where it is obtained from the Palmyra palm, *Borassus flabellifer* L. Palmetto fiber is also used extensively in whisk brooms.

Although the palmetto has been utilized mainly for brush fiber, it has a number of other minor uses. In preparing the finished fiber, there is some waste material obtained in combing and shredding, and some from cutting to specified market lengths. This waste fiber has been sold for upholstery, but little is used for that purpose at present. The

waste has been used also for bulk heads for docks, and has been suggested as a substitute for coir in matting. However, one manufacturer who tried the waste stated that it is not so flexible nor so strong as coir.

The buds of *Sabal palmetto* have been prized by the Seminole Indians as an article of food, for which purpose they are boiled after being removed and trimmed. They are pickled and preserved in Florida at present to a limited extent. The terminal tufts of young uncurled leaves are removed by the Seminole Indians to ship to churches for use on Palm Sunday. Removal of the leaves for this purpose does not kill the plant as does removal of the bud. Handicraft specialists of the Florida State Markets have encouraged use of the leaves for basketry. In some cases the entire leaf is made into a fan, but in other cases the segments of the leaf are stripped lengthwise into strips about a half inch wide, which may be dyed and then woven into baskets or similar articles. The leaves have also been shredded and used to some extent for stuffing cheap mattresses; and as a substitute for hair in plastering and stucco work. They have also been used as a substitute for broomcorn for brooms, and at one time a company was organized to make twines and rugs from shredded segments of the leaves.

The rootstocks contain tannin, and various efforts have been made to extract this component for use in tanning leather, but thus far the work has not proved to be profitable. The trunks are used for small wharves or docks, because it is stated that they are practically immune to injury from the teredo, a water mollusk that bores into other woods used in salt water.

Saw Palmetto

The common saw palmetto, *Serenoa repens* (Bartr.) Small, is found throughout the State of Florida, in southern Georgia and to some extent in Alabama, Louisiana and South Carolina. It usually grows on uncultivated tracts or in the undergrowth of pine lands. It is a low shrub usually with a recumbent trunk that frequently may be just under the soil. The leaf stalks are slender but bordered with small sharp spines. The leaves are fan-shaped.

Many attempts have been made to utilize this plant to some economic advantage. The leaves and stem fibers have been used to some extent in the past as an upholsterer's filler, in brushes and in plaster, but no extensive utilization of importance has developed.

The berries are employed in medicine and have been collected and handled by one or two firms in Florida. Their value is believed to be low, and just covers the cost of collecting.

During World War II a factory was erected in Florida to utilize the pulp from the root-like trunks in cartridge plugs and for wall board. The fiber removed from the trunks was experimentally prepared for cordage, but by abaca and sisal standards it was of low grade for that purpose.

Spartina Grass

In the United States the most important broom or brush fiber plant material is broom corn of which there is grown annually approximately 300,000 acres that produce 40,000 tons of broom material. The brooms are used in nearly every household, and in many industrial mills. Spartina grass from Florida, Louisiana and Missouri, nolina shredded leaves from New Mexico and rice straw of domestic origin are substitutes for broom corn. Utilization of the last two is sporadic, but Spartina grass apparently has been able to compete year after year until it deserves the name of an industry.

This plant, *Spartina spartinae* (Trin.) Merr., is a grass that grows in large

dense tufts without rhizomes; the culms are stout, one to two meters tall; blades are narrow, firm, strongly involute; spikes are short and appressed, closely imbricate, forming a dense cylindric inflorescence 10 to 30 cm. long; spikelets are closely imbricate, six to eight mm. long; glumes are hispid-ciliate on the keel, the first shorter than the lemma,

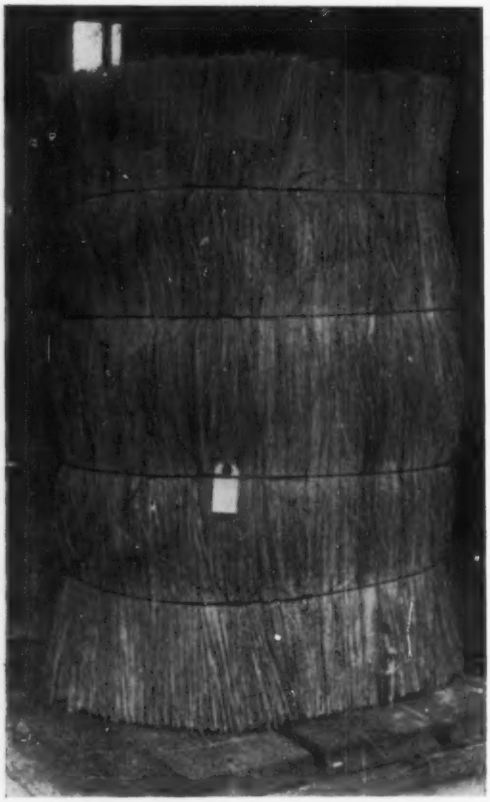


FIG. 1. A bale of fibers obtained from Spartina grass, *Spartina spartinae*, to be used primarily as a substitute for broom corn in the manufacture of brooms.

the second usually a little longer. The plant is distributed in marshes, swamps and moist prairies near the coast from Florida to Texas and eastern Mexico.

Several other species of spartina have also been utilized in the United States for many years. The culms have been used in brooms, matting, paper, stock food and as a packing material. Reports indicate that they may have potential high value for paper. The conclusions of an analysis by a paper mill at Quincy, Illinois, in 1906 was that spartina fiber was superior to esparto, *Stipa tenacissima* L., for paper. The mill at Quincy used from 3,000 to 7,000 tons annually for making box-board at the beginning of the 20th century.

Large areas of spartina are found near Titusville, and on Meritt Island, Florida, where the grass has been utilized for many years. It has been collected to some extent between Lakeport and Brighton, Florida. It substitutes for broom corn in the center of the broom, and utilization in this capacity has been primarily in periods when broom corn was high priced.

Arrangements are made with land owners where this wild grass may be found in large stands for permission to harvest it. In some cases the lease right amounts to 50¢ per ton for the privilege of harvesting. The harvesting may be and is performed the whole year round. In this respect it differs from the harvesting of Missouri grass or "Rippey", *Spartina pectinata* Link., which is harvested seasonally for a few weeks in the summer in Missouri. In Florida the old stands are burned over in order to get a new growth of green culms without a mixture of older culms. It requires about 90 days for a new growth after burning before harvesting. After two or three harvestings the stand is believed to be poorer. On uplands in the vicinity of Titusville the stands may be weedier. As far as is known, the grass has not been cultivated, although plans to conduct tests toward that end have been made. Tufts covered for several months with water die.

Harvesting is performed with a hand sickle. In Florida the harvesters received $1.75 per 100 pounds of dry straw in August, 1946. Two harvesters may cut one to one and a half tons of dry culms per day. After cutting, the culms are

placed on top of the stubble of the tuft to dry. Drying and curing require about a week, after which the harvesters place the culms in large bundles, cover the bundles with burlap and then carry them to the nearest road. In southeastern Louisiana the harvesting methods were the same a number of years ago, but the grass, *S. pectinata*, after harvesting was moved by small barges to the nearest highway. The harvesters were forced to wear hip boots and were unable to cut during high tides, as the grass was then partly under water.

The advantage of collecting spartina in the area between Lakeport and Brighton, Florida, has been that it may be harvested with a binder, a practice that is permitted by dry ground in more accessible areas.

Hand harvesters, to facilitate bundling, have been observed to use a light wooden saw horse with projecting upright legs on which burlap was stretched and the straw then placed upon the burlap. The harvester's job is complete when he carries the dry straw to a roadway, whence it is trucked to warehouses. There, in crude, inexpensive but effective presses, it is made into cylindrical bales, pressure being applied by tightening ropes around the straw. The bales weigh about 220 pounds and are 36 inches long and about 28 inches in diameter. The straw is placed in the bales, one handful at a time, alternating the heads with respect to direction. The loose ends of grass sticking out at the ends of the cylindrical bales are cut off with a pair of garden or hedge shears, and the bale ends may be pounded even with a large wooden paddle, on one side of which there are pins to make a hackle. The hackle is used in straightening any crooked culms.

A bright colored straw is preferred. Periods of wet weather darken the color. The culms, while flat and about three-eighths inch wide during growth, curl upon harvesting. The Florida grass has wider leaves than the Louisiana and Missouri grasses and has been said to be slightly less wearable. In brooms, used mainly in the northeastern States, it makes up over 50% of the broom surrounded by broomcorn on the outside, and usually sells for about one-third the price of broomcorn. The total production for Florida is approximately 90 freight cars in good years. Before the war a car held ten tons, but during the war cars were loaded to 14 tons.

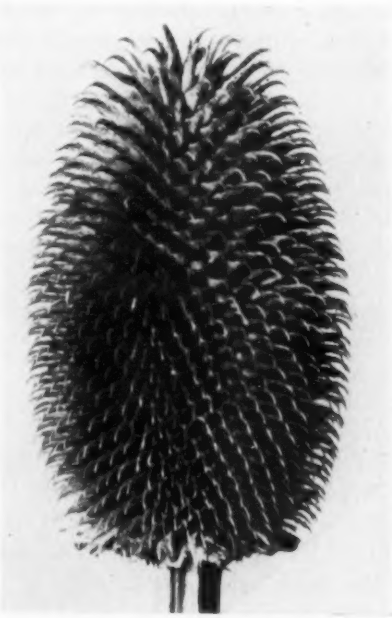


FIG. 2. A bur of Fuller's teasal, *Dipsacus fullonum*, the ripened flower heads of which have long been used in Europe and America to raise the nap of cloth.

This grass is known in the Florida area as "switch grass", and it may grow mixed with a sedge, ***Fimbristylis castanea*** (Michx.) Vahl, which may account for 3% of the total production. The sedge is considered to be of better quality than the spartina.

Teasels

Teasels play a generally unappreciated part in the manufacture of many

textile fabrics, for which purpose they are cultivated to form a small but highly specialized agricultural industry. The stiff, needle-like, modified leaf bracts which form below the flowers in the head or bur make the bur of value in textile manufacturing where the needles of the bur are used to raise the "nap" or "pile" of the cloth to produce desired finishes on specific fabrics. The soft warmth of blankets may partly result from such a finish. Before the development of machines and steel pins in combs, the woolen industry dressed all cloth with teasels, but today steel brushes are used for raising the nap on most fabrics. However, teasels have not been entirely discarded, and they are cultivated and produced in Europe and to some extent in this country to serve an essential need. Teasel burs have been stated to be superior to steel combs for very fine cloths and where the nap is raised under damp conditions that may cause steel pins to rust. Steel combs are too rigid and do not have the "give" of the teasels.

The teasel plant, *Dipsacus fullonum* L., is called Fuller's or Draper's teasel. It is not native to the United States but to southern Europe. Rarely is it found growing wild near woolen mills in our eastern States. It differs from the wild, common or card teasel, *Dipsacus sylvestris* Mill., naturalized from Europe and found in many waste areas in the United States, by having hooked scales or spines and not straight ones. The plants are biennial, producing burs or flower heads the next year after the seeds have been planted. The plants the first year are leafy and grow about a foot high, but the second year fruiting, prickly, erect shoots grow up five to seven feet tall. It is upon the ends of these shoots and their lateral branches, which are encouraged, that the burs are formed.

Teasels are cultivated principally in Germany, France, Spain, England and the United States. However, they constitute a relatively minor industry in these countries, and a crop failure in one country would affect the available supplies and prices in other countries. It has been reported that teasels have been raised near the town of Skaneateles, New York, since the year 1840, and in Oregon since 1900. Domestic teasels have to compete in the market with foreign teasels, normally imported from France, and must overcome the inherent tradition in many old mill men that foreign products are superior to our own.

The quality of teasel is measured by its elasticity or "give", weight or size, retention of spines, wearing qualities and brittleness. These characteristics are believed to be greatly influenced by planting seed of a proper variety and by selection of a growing region having favorable soils and climatic conditions. Dry harvest seasons are generally preferred wherever teasels are grown, for such weather insures not only proper maturing of the burs on the plant but curing after harvest. Nature has been credited with curing the burs better than can be achieved by artificial drying. On the other hand, moderate or ample rainfall is desirable during the spring and early summer. Long periods of incessant rains or damp weather cause water to lodge in the bracts of the bur, which creates a weakening if not a rotting of the bur. Variability of the weather results in the quality of the teasels varying from year to year. In general, the climates where teasels are grown in Europe and Oregon are milder than in our northern States. The teasel-growing seasons in the vicinities of Marseilles, France; around Valencia and Alicante, Spain; Somersetshire, England; and to some extent in Oregon are relatively long, which seems to insure maximum development of the burs the second year, differing from the quick growing season due to late winters which are experienced in many northern regions.

Teasels are generally grown on

medium to heavy soils that often are calcareous. In England the soil is described as a rich heavy clay soil. In New York they are cultivated on slopes having heavy soils but soils with adequate drainage. Some are grown upon lighter soils, but such soils may have much silt and available sub-surface moisture, as occurs on the silt bottoms of the Rhone river in France. Soil drainage and freedom from weeds have been stressed by growers.

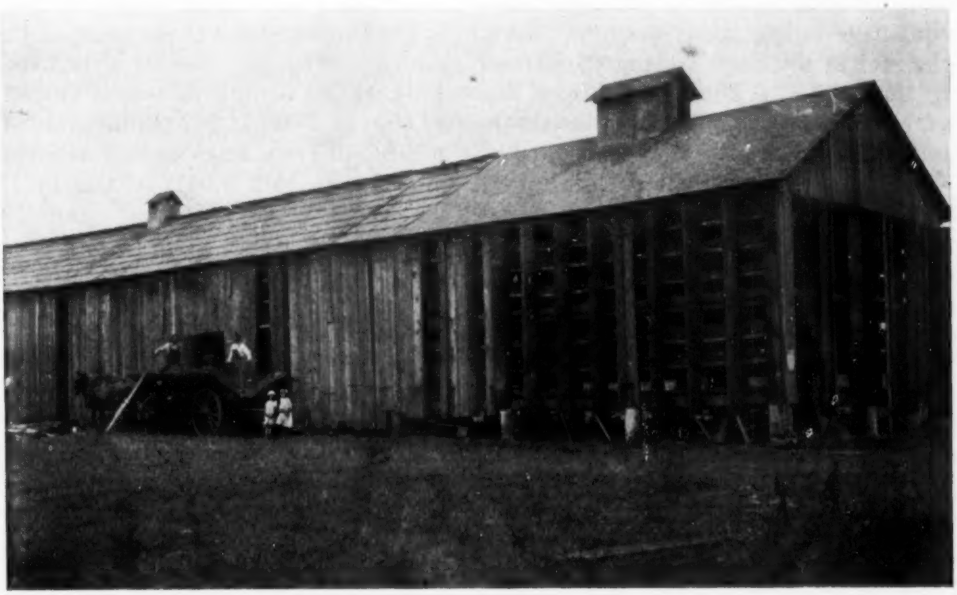


FIG. 3. Teasels after harvesting are dried in well ventilated barns. They are placed in layers three or four inches deep upon numerous scaffolds.

Planting may be in beds from which the small seedlings are later transplanted to the field. In other cases the seed is planted directly in rows approximately three feet apart which are adapted to cultivation using standard farm equipment. The plants are later thinned in the row to spacings of 10 to 12 inches between plants. If planted in beds the seedlings are later transplanted in rows three feet apart and spaced 10 to 12 inches in the rows. Corn has been recommended for planting in the same row with the teasels the first year. This insures some return the first year and may not be very detrimental to the teasels. The corn at harvest is cut to leave a tall stalk that serves to collect and hold snow to protect the teasel plants from winter killing. In some cases only one-third of the area planned for teasels is sown in rows. The small seedlings thinned out from this planting are sufficient to plant the remaining two-thirds of the field. Approximately one to two pecks of seed are sown per acre. Although a great deal is not known in reference to cultural practices, some growers have preferred to grow teasels after corn or beans. This would result in clean cultivation the previous year to help eliminate weeds from crowding out the small teasel seedlings that follow. Fall wheat can easily follow teasels. The second year the main teasel stems may be cut off two feet above the ground to cause branching to insure greater production of burs.

The burs are harvested by cutting them off, together with three to four inches of the stem. It is usually necessary to go over the field two or three times, or in some cases six times, because

they ripen unevenly. They are collected in large baskets which when filled may be emptied on large rack-type wagons for hauling to the drying sheds. The drying sheds provide adequate ventilation, as the teasels are spread in thin depths, two to three inches deep, upon numerous racks or scaffolds. Such drying prevents heating and rotting of the burs. A deteriorated bur when placed in contact with cloth might lose its hooks, making it useless. Harvesting should begin as soon as possible after the blossoms have fallen, about the first of August, for at this time seeds at the bottom of the head are almost mature. The harvester needs a sharp knife or shears and wears gloves to protect his hands.

The main stalk produces the largest and strongest teasel, known as the "king", the main terminal branches produce the "queen" teasels of medium size, and the smallest ones growing on secondary branches are called "button" teasels. It is necessary for the producer to sort his teasels and grade them for size in order to satisfy market demands and for the performance of different degrees of work. Considering the climatic and soil restrictions, and the great amount of labor in planting or transplanting the crop, cultivation for two years, hand harvesting several times, the special equipment for drying and sorting and marketing to a small competitive market, the production of teasels is a highly specialized activity that does not attract the average farmer. Those who have grown teasels for many years have been successful, but they have had their lean years, as would be experienced with other crops.

The yield of teasels in some cases is recorded in numbers and in other cases by weight. Each is influenced to some extent by the size of the burs resulting from the variety grown. Yields of 100,000 to 200,000 heads per acre have been reported. The smaller number is for America. In weight the average yield under favorable conditions may vary from 800 to 1,500 pounds of heads per acre.

The price varies in accordance with the demand. When the fashions cause an increased demand for broadcloths there is a correspondingly increased demand for teasels, or if serges and rough woolens are in favor, there is less demand for teasels. Normally the largest producer of a dozen or more growers has cultivated less than a hundred acres of teasels each year in the United States.

The United States Department of Commerce reports that our imports were in 1934, 13,767 pounds of teasels valued at $4,090; in 1939, 48,962 pounds valued at $8,610, all from France; and as a result of the war only 1,041 pounds in 1942 valued at $504, which all came from Argentina.

In use the teasels are arranged on a cylinder in such a way that the cloth passes slowly over them while the cylinder or "gig", as it is called, revolves. Thus the recurved hooks catch the fibers of the cloth, causing them to stand up from the surface to form a nap which may be sheared to bring it to a uniform length. Great care has to be taken in mounting the teasels so they will work uniformly and not produce stripiness by bearing heavier on the fabric at one point than at another. The teasel hook is strong enough for the work and yet elastic enough to "give" before breaking the cloth. Teasels are used for raising the nap on very fine woolen cloth such as broadcloth, high quality overcoating, camelhair topcoats, high quality woolen blankets, billiard cloth, piano cloth and many other industrial fabrics.

One additional use should be mentioned for teasels, as many people are possibly more familiar with the use of them in dry floral wreaths than by woolen manufacturers. Floral teasels are colored for dry wreaths, and the price has been about a third of the price of burs sold to clothing manufacturers.

The Distribution, Abundance and Uses of Wild Drug Plants in Oregon and Southern California

Where the accessibility, prevalence and variety of native medicinal plants may well serve as the basis of an American crude drug industry.

ERNST T. STUHR

Frank Nau Manufacturing Chemists, Portland, Oregon

Introduction

NATURE has endowed the Pacific Slope of the United States with unusually favorable climate and soils for plant growth. Throughout this vast region which extends from Mexico to Canada there is an abundance of varied plant life, including a number of important drug plants, some of which are native to the Pacific Coast States and others of which have been introduced there. Some of the native plants abound only in the woods and on the hillsides; others are also under cultivation in certain localities. A few commercial projects in the area have developed into worthwhile proportions, but the Pacific Coast as a whole is still a virgin field from the standpoint of scientific investigation and development of medicinal plant resources. The potential possibilities for a crude drug industry in the area should be unlimited.

Surveys under the auspices of the Committee on Botany and Pharmacognosy of the National Research Council and by chemurgic committees show an impressive list of significant native wild medicinal and allied economically important plants. This article considers only the regions where these surveys have been completed, namely, Oregon and southern California. Similar studies in northern California and the State of Washington are still in progress. A few of the more important plants which thrive in the region covered by the surveys so far, either growing in their native habitats or being cultivated successfully on a commercial basis, are cascara, ginseng, goldenseal, belladonna, peppermint, flax, barberry, juniper and ergot. More specifically, the natural distribution, abundance and uses of these, and preparations of the drugs which they provide, may be listed as follows:

Native Wild Medicinal Plants of Oregon by Counties

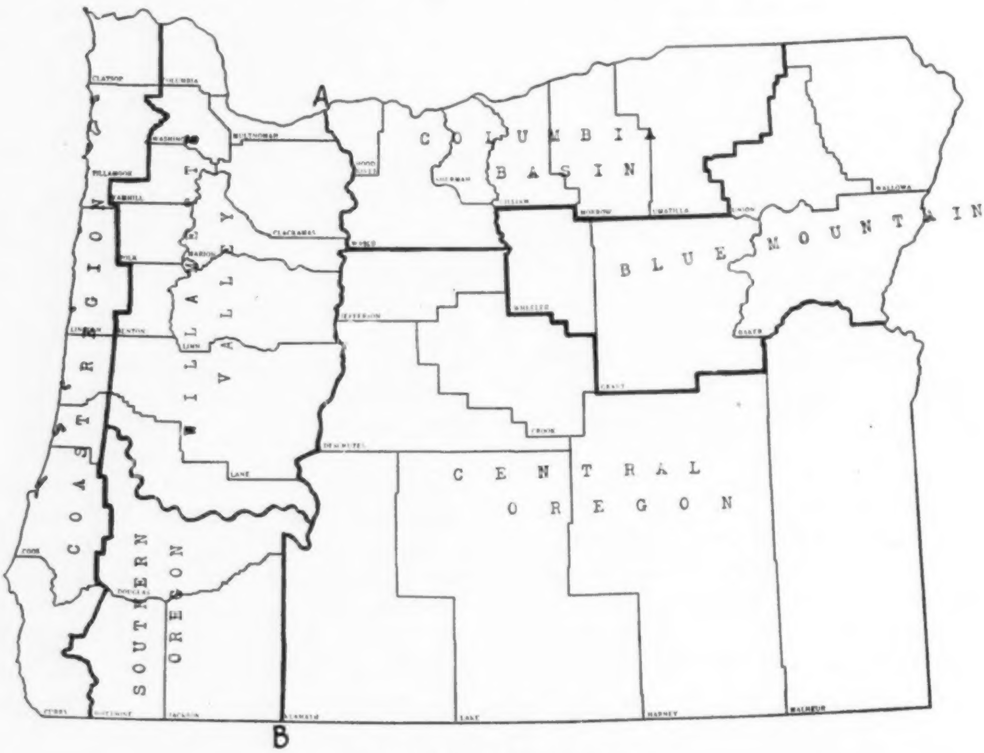
BAKER COUNTY		
Arctostaphylos Uva-ursi (L.) Sprengel	Dry north slopes	Not abundant
Berberis	Most wooded slopes	Not abundant
Chimaphila umbellata (L.) Barton	North slopes, higher elevations	Not abundant
BENTON COUNTY		
Berberis	Wooded slopes	Not abundant
Cytisus scoparius (L.) Link	Waste lands, central to western area	Fairly abundant
Digitalis purpurea L.	Western half of county, woodlands, roadsides	Fairly abundant
Rhamnus Purshiana De Candolle	Throughout foothills of Coast Range	Fairly abundant

CLATSOP COUNTY

Berberis	General over county	Abundant
Cytisus scoparius (L.) Link	Western part of county	Abundant
Digitalis purpurea L.	General over county	Abundant
Rhamnus Purshiana De Candolle	Scattered generally over county, more abundant in eastern part	Quite abundant

COLUMBIA COUNTY

Berberis	Rich woodlands and cut-over lands	Abundant
Cytisus scoparius (L.) Link	Cut-over lands and northern part of county	Abundant
Digitalis purpurea L.	Northern part	Abundant
Rhamnus Purshiana De Candolle	Rich, moist woodlands	Abundant



DIVISIONS OF OREGON

Geographically the State is divided into two divisions, commonly known as Eastern and Western Oregon, indicated by the line AB or Cascade range of mountains. Eastern Oregon has dry summers and cold winters. Western Oregon has temperate summers and mild winters with an abundance of rainfall from October to May.

Climatologically the State is sub-divided into six sections: Coast Region, Southern Region, Willamette Valley, Columbia Basin, Blue Mountain Division and Central Oregon.

COOS COUNTY

Berberis	General distribution on higher land	Abundant
Cytisus scoparius (L.) Link	General distribution on sandy and glade land	Fairly abundant
Digitalis purpurea L.	Woodland slopes	Scarce
Rhamnus Purshiana De Candolle	General over county	Abundant

CURRY COUNTY		
Arctostaphylos Uva-ursi (L.) Sprengel	All parts of county; on poorer lands and ridges not capable of producing timber	Very abundant
Berberis	On burnt-over areas and range land	Abundant
Chimaphila umbellata (L.) Barton	Occurs on higher ridges	Not abundant
Cytisus scoparius (L.) Link	Only where introduced as ornamental shrub, spreads to wild state if not controlled	Not abundant
Digitalis purpurea L.	All parts of county, on open and range lands, along roads, rivers, *etc.*	Very abundant
Rhamnus Purshiana De Candolle	Throughout county in all areas of better soil	Abundant
DESCHUTES COUNTY		
Berberis	Dry woods, western part of county	Not abundant
Chimaphila umbellata (L.) Barton	Dry woods, western part of county	Abundant
DOUGLAS COUNTY		
Berberis	In all sections of county	Abundant
Chimaphila umbellata (L.) Barton	Higher elevations on west slope of Cascades	Not abundant
Cytisus scoparius (L.) Link	In coast and Elkton areas	Not abundant
Digitalis purpurea L.	West of Range 8, moist lands, usually found on west slope of coast range	Abundant
Rhamnus Purshiana De Candolle	West of Range 7, moist wood lands, scattered east of Range 8 but not in quantity	Abundant, often localized
GRANT COUNTY		
Arctostaphylos Uva-ursi (L.) Sprengel	Semi-dry, yellow pine woods	Fairly abundant
Berberis	Moist to semi-dry woods	Abundant
Chimaphila umbellata (L.) Barton	In Jack Pine country	Abundant
Rhamnus Purshiana De Candolle	Rich, moist woodlands	Not abundant
HARNEY COUNTY		
Berberis	Small amount scattered over northern end of county	Scarce
JOSEPHINE COUNTY		
Arctostaphylos Uva-ursi (L.) Sprengel	Moist shady woods	Variously scattered, south and west parts
Berberis	Forest along stream banks	Abundant
Chimaphila umbellata (L.) Barton	Forest on high mountain sides and top of peaks	Plentiful in southern and southwestern part; also northern part of county
Digitalis purpurea (L.)	Woods and hillsides	Very few in northern and eastern parts
Rhamnus Purshiana De Candolle	Woods along stream banks	Nearly extinct, few remaining have been peeled or killed
KLAMATH COUNTY		
Berberis	Entire county north and west of Klamath Falls, moist woodlands	Fairly abundant

LANE COUNTY		
Arctostaphylos Uva-ursi (L.) Sprengel	Coast section	Abundant
Berberis	All over the county	Abundant
Cytisus scoparius (L.) Link	All over the valley and coast section	Fairly abundant
Digitalis purpurea L.	West of Coast Range	Abundant
Rhamnus Purshiana De Candolle	All over the county	Abundant
LINCOLN COUNTY		
Berberis	Found in most parts of the county in the hill lands	Fairly abundant
Cytisus scoparius (L.) Link	Found along the roads, in towns along the coast and in central part of the county	Abundant
Digitalis purpurea L.	Found in most parts of the county in the wooded hill lands	Abundant
Rhamnus Purshiana De Candolle	Fairly well distributed over the county on hill land	Fairly abundant
LINN COUNTY		
Berberis	Scattered throughout county, not in commercial quantities	
Cytisus scoparius (L.) Link	Scattered, not commercial	
Rhamnus Purshiana De Candolle	Abundant along streams and river bottoms	
MARION COUNTY		
Berberis	In woodland areas in eastern part of county	Not abundant
Cytisus scoparius (L.) Link	Scattered through the county	Not abundant
Rhamnus Purshiana De Candolle	In woodland areas in eastern part of county	Abundant in some localities
MORROW COUNTY		
Arctostaphylos Uva-ursi (L.) Sprengel	South part	Not abundant
Berberis	Dwarf species, south end of county	Some, but not abundant
Chimaphila umbellata (L.) Barton	Scattered through timber, mostly on north slopes, south end of county	Fairly abundant
MULTNOMAH COUNTY		
Arctostaphylos Uva-ursi (L.) Sprengel	East end of county and central part	Not abundant
Berberis	All high ground in county	Scattered
Cytisus scoparius (L.) Link	Scattered all over, domestic plantings as ornamentals	
Digitalis purpurea L.	East of Gresham	Plentiful in some communities
Rhamnus Purshiana De Candolle	East end of county	Scarce
POLK COUNTY		
Berberis	Timber areas and general	Abundant
Cytisus scoparius (L.) Link	General	Abundant
Rhamnus Purshiana De Candolle	Timber areas	Numerous
TILLAMOOK COUNTY		
Berberis	Moist woodlands	Abundant
Cytisus scoparius (L.) Link	Sandy areas	Some
Digitalis purpurea L.	Throughout county	Abundant
Rhamnus Purshiana De Candolle	Throughout county	Not abundant

UMATILLA COUNTY		
Arctostaphylos Uva-ursi (L.) Sprengel	Found associated with Ponderosa pine, Douglas fir and Lodgepole-pine stands	Common
Berberis	Found on rocky slopes and canyon bottoms	Not abundant
Chimaphila umbellata (L.) Barton	Found associated with Ponderosa pine, Douglas fir and Lodgepole-pine	Common
UNION COUNTY		
Berberis	Woodlands	Abundant
WALLOWA COUNTY		
Berberis	In lower elevations throughout the county	Quite abundant
Chimaphila umbellata (L.) Barton	Some present on upper alder slope and probably in similar places on the edge of the timber throughout the county	Fairly abundant
Digitalis purpurea L.	In high mountain regions	Not abundant
Rhamnus Purshiana De Candolle	Occurs in the lower canyons throughout the county	Fairly abundant
WASCO COUNTY		
Arctostaphylos Uva-ursi (L.) Sprengel	Moist woodlands and wash lands	Not abundant
Berberis	In creek beds	Abundant
Cytisus scoparius (L.) Link	Small amount in Mosier	Not abundant
YAMHILL COUNTY		
Berberis	Moist woodlands	Abundant
Cytisus scoparius (L.) Link	Dry areas	Not abundant
Rhamnus Purshiana De Candolle	Moist woodlands	Not abundant

Native Wild Medicinal Plants of Southern California by Counties

In making the surveys of the distribution and abundance of native medicinal plants in Southern California, the natural boundaries of the region were taken into consideration. Approximately one-third of the State's area was covered, as portrayed by the accompanying map. Included are certain drug-yielding plants which have become naturalized, following escape from gardens. A few of the plant species are widely scattered throughout the entire section.

Acacia Farnesiana (L.) Willd.		
San Diego	One mile SW of Otay	Not abundant
Acacia Greggii A. Gray		
Riverside	Colorado desert region	Not abundant
Achillea Millefolium L. var. *lanulosa* (Nutt.) Piper		
Western counties	In moist places in the pine belt of all mountains, also along the coast	Abundant
Adiantum pedatum L.		
Santa Barbara	Damp shady places, coast ranges	
Anethum graveolens L.		
Los Angeles	Escape from gardens, Long Beach, Los Angeles	Not abundant
Apium graveolens L.		
Riverside, San Bernardino, San Diego, Los Angeles	In moist places (Ballona, Arlington, Chino, Otay, Downey, Pomana, San Jacinto, Romona)	Moderately abundant

Apocynum androsaemifolium L. Riverside, San Bernardino	At 6,500–9,500 feet, San Bernardino Mts.	Occasional
Apocynum cannabinum L. var. *glaberrimum* DC. San Diego, Los Angeles, Riverside	Laguna Mts., Palomar Mts., San Bernardino Mts., San Fernando Valley	Occasional
Aralia californica Wats. Riverside, Orange	Shaded canyons, 2,500–5,000 feet, south face of San Bernardino and San Gabriel Mts., Santa Ana Mts. and northward	Moderately abundant

SOUTHERN CALIFORNIA

The counties in which surveys of wild medicinal plants have been completed.

Arctium Lappa L. Riverside	Sparingly naturalized as at Riverside	Not abundant
Arctostaphylos glauca Lindl. Western counties	Mountain foothills up to 3,500 feet (sometimes higher); to central California	Abundant
Brassica Kaber (DC) Wheeler San Bernardino, Riverside	Claremont, Upland, Moreno, Beaumont, Coachella	Not abundant
Brassica juncea (L.) Czerniaew Riverside	San Bernardino Valley	Moderately abundant
Brassica nigra (L.) Koch. Western counties	On dry slopes and in valley grain fields	Moderately abundant

Cannabis sativa L. San Diego, San Bernardino	Upland, San Diego	Moderately abundant
Carthamus tinctorius L. Los Angeles	Antelope valley	Not abundant
Centaurea Cyanus L.	Escape from gardens	Not abundant
Chenopodium ambrosioides L. var. *anthelminticum* (L.) Gray Coast counties	Frequent, damp places, western slopes of mountains, into valleys	Abundant
Chimaphila umbellata (L.) Barton, also var. *occidentalis* Blake Riverside, San Bernardino	On dry slopes in shade, at 7,000 to 10,000 feet, San Jacinto Mts. (north fork of Tahquitz Creek, Dark Canyon) and San Bernardino Mts. (Dollar Lake region)	Moderately abundant
Cichorium Intybus L. Los Angeles, San Diego	Low waste places, orchards, vacant lots	Moderately abundant
Conium maculatum L. San Bernardino, Los Angeles	In moist places (San Bernardino, Pasadena, El Monte, Los Angeles, Long Beach)	Not abundant
Coriandrum sativum L. Los Angeles, San Diego	Escapes from gardens (San Diego, Los Angeles, Anaheim)	Occasional
Cornus californica Mey.	Along streams and underbrush of mountain regions, up to 7,000 feet; to central and northern California	Occasional
Cornus glabrata Benth. Riverside, San Diego, Ventura	Rare in So. Calif., Warners Hot Spring, Hemet Valley in San Jacinto Mts., Mt. Pinos, near Gaviota Pass; to northern Calif.	Not abundant
Cornus Nuttallii Aud. San Diego, Riverside, San Bernardino	In damp places in mountains at 4,000–7,000 feet (Cuyamacas, Palomars, Dark Canyon of San Jacinto Mts., San Bernardino Mts., Cascade Canyon in San Gabriel Mts.)	Occasional
Datura Stramonium L. Los Angeles	Santa Monica, Playa del Rey	Occasional
Datura Tatula L., also *D. meteloides* Dunal San Bernardino, Los Angeles	San Bernardino north of Claremont, San Dimas Canyon	Not abundant
Dryopteris Filix-mas (L.) Schott. Riverside	Holcomb valley, San Bernardino Mts.	Not abundant
Eriodicyton californicum (Hook & Arn.) Torr. var *lanatum* Brand. Riverside, San Diego	Mountains along western edge of Colorado Desert, from Santa Rosa Mts. south	Moderately abundant

Euphorbia Lathyrus L. Riverside	In damp waste places, San Jose hills, San Antonio Canyon, San Jacinto River	Occasional
Foeniculum vulgare Gaertn. Western counties	Waste places in mountain valleys	Moderately abundant
Fremontia californica Torr. Riverside, San Bernardino, Kern, Los Angeles	Dry slopes at 3,000–6,000 feet, occasional western edge Colorado Desert and southern slopes San Bernardino and San Gabriel Mts.; more abundant on slopes bordering western half of Mohave Desert; north to central Calif.	Moderately abundant
Fumaria officinalis L. San Bernardino, Riverside	Orchard weed, Ontario, Upland, Banning	Occasional
Galium angustifolium Nutt. Kern, San Louis Obispo, Santa Barbara	Common on dry slopes and among underbrush, below 6,000 feet, west of the Sierra range to coast	Moderately abundant
Galium Aparine L. San Bernardino	On shaded banks below 7,500 feet; on the islands off the coast; occasional on deserts (Providence Mts.)	Occasional
Garrya Fremontii Torr. San Diego, Orange	Central Calif., also in Laguna Mts. and Santa Ana Mts.	Not abundant
Grindelia hirsutula Hook & Arn. var. *subintegra* Steyermark Ventura	Open hillsides; vicinity of Ojai	Moderately abundant
Grindelia robusta Nutt. Orange, Santa Barbara	Clay soil of coastal slopes and flats, and wet places on coastal mesas and low ground, from Orange Co. north to Santa Barbara Co.; around Santa Barbara	Moderately abundant
Grindelia squarrosa (Pursh) Dunal var. *serrulata* (Rydb.) Steyermark Los Angeles, Kern	Desert slopes of San Gabriel Mts. and Antelope Valley	Moderately abundant
Hedeoma thymoides Gray San Bernardino	Dry slopes at 3,000–5,000 feet in Providence and Clark Mts.	Not abundant
Helianthus annuus L.	Common as weed in waste places and old fields	Abundant
Lobelia cardinalis L. San Diego, Los Angeles	In boggy places below 6,000 feet	Occasional
Malva sylvestris L. San Bernardino	Sparingly escaped from gardens, (Redlands)	Not abundant
Marrubium vulgare L.	Common weed in old fields and waste places, throughout state	Moderately abundant
Mentha arvensis L. San Bernardino, Riverside, San Diego	Marshy places, San Bernardino, Riverside, Cuyamaca Mts.	Not abundant

Mentha citrata Ehrh. San Bernardino, Riverside	Escaped from gardens, mecca, San Bernardino	Abundant
Mentha piperita L. Los Angeles	In moist places, near Los Angeles; also Bay region	Not abundant
Mentha spicata L. Coast counties	In wet places	Moderately abundant
Nepeta Cataria L. San Bernardino, Riverside, Los Angeles	Waste places in Oak Glen, San Bernardino, Riverside, Claremont	Moderately abundant
Plantago lanceolata L. Coast counties	Weed in lawns and waste places; pest in pastures	Abundant
Plantago major L.	Weed in moist places	Abundant
Portulaca oleracea L.	Weed in low or waste places	Abundant
Prunella vulgaris L.	Naturalized in lawns	Moderately abundant
Rhamnus californica Esch. Riverside	In canyons and washes and in undergrounds, up to 7,000 feet on south slopes of San Bernardino and San Gabriel Mts. through western wet slopes to Mendocino County	Abundant
Rhus glabra L. Riverside	In Chino Canyon, San Jacinto Mts.	Not abundant
Ricinus communis L. San Louis Obispo, Santa Barbara, Ventura	Frequent in waste places, mountain foothills and valleys	Moderately abundant
Rumex Acetosella L. Western counties	Damp grassy places in the mountains and along coast	Abundant
Rumex crispus L. Western counties	Troublesome weed in low waste places	Abundant
Saponaria officinalis L.	Escaped from old gardens, especially in cool damp places	Moderately abundant
Senecio vulgaris L.	Orchard and garden weed, as well as waste places	Abundant
Styrax officinalis L. var. *fulvescens* Munz & Johnson San Diego, San Bernardino, Los Angeles, Santa Barbara	Partly shaded slopes below 5,000 feet in Foster, Mesa Grande, Henshaw Dam, Palomar Mts., Trabuco Canyon; canyon above San Bernardino, Glendale, Santa Ynez Mts.	Occasional
Tamarix gallica L. Los Angeles, San Bernardino, Riverside, Imperial, Inyo	Dunes and in washes, San Gabriel River, Wilmington, Ontario, Furnace Creek (Death Valley), Salton Sea, Thousand Palms	Moderately abundant
Verbascum Thapsus L. San Diego	Moist places, Palomar Mts., throughout state	Abundant

Uses of the Wild Medicinal Plants Listed in the Foregoing Survey

GENUS	PARTS USED	PREPARATIONS	THERAPEUTIC QUALITIES[1]
Acacia	Exudation from stems and branches	Mucilage, infusion	Demulcent, emusifying agent
Achillea	Entire plant	Infusion	Aromatic bitter, diaphoretic
Adiantum	Fronds	Syrup, infusion	Demulcent, stimulant, expectorant
Anethum	Fruit	Oil	Stimulant, aromatic, carminative
Apium	Fruit	Oil	Stimulant, condiment
Apocynum	Tuberous roots	Tincture, liniment	Stimulant to sensory nerves, depressant
Aralia	Rhizomes, roots	Compound syrup	Stimulant, diaphoretic, alterative
Arctium	Root	Fluidextract	Diaphoretic, diuretic, alterative
Arctostaphylos	Leaf	Fluidextract	Diuretic, mild disinfectant to urinary tract
Berberis	Rhizome and roots	Fluidextract	Bitter tonic
Brassica	Seeds	Oil	Rubefacient, counterirritant, stimulant, condiment
Cannabis	Flowering tops	Extract, fluidextract	Cerebral stimulant, analgesic, narcotic, sedative
Carthamus	Florets	Infusion	Diaphoretic, laxative, dye
Centaurea	Entire plant	Infusion	Mild astringent
Chenopodium	Fruits, tops	Oil	Anthelmintic
Chimaphila	Leaf	Fluidextract	Diuretic, astringent, mild disinfectant to urinary tract
Cichorium	Rhizomes, roots	Infusion	Simple bitter, laxative, diuretic
Conium	Unripe fruit	Extract	Motor depressant, anodyne
Coriandrum	Fruit	Oil	Aromatic stimulant, corrective, condiment
Cornus	Root-bark	Fluidextract	Tonic, astringent
Cytisus	Dried tops	Infusion, Sparteine	Diuretic in dropsy, cardiac depressant
Datura	Leaves, flowering tops	Extract fluidextract, tincture	Relax bronchial muscles, asthma, anodyne
Digitalis	Leaves	Tincture, powder	Cardiac stimulant, tonic, diuretic
Dryopteris	Rhizome, stipes	Oleoresin	Taenifuge, anthelmintic
Eriodictyon	Leaves	Fluidextract, aromatic syrup	Expectorant, mask bitter tastes
Euphorbia	Entire plant	Fluidextract, compound Elixir	In asthma preparations
Foeniculum	Fruit	Oil	Stimulant, carminative, galactagogue, condiment
Fremontia	Outer bark, inner bark	Poultice	Demulcent
Fumaria	Leaves, juice	Infusion	Tonic, diuretic, laxative, cholagogue
Galium	Entire plant	Infusion	Diuretic, mild laxative, refrigerant
Garrya	Leaves	Infusion	Tonic, antiperiodic

GENUS	PARTS USED	PREPARATIONS	THERAPEUTIC QUALITIES[1]
Grindelia	Leaves, flowering tops	Fluidextract	Stimulating expectorant in bronchitis
Hedeoma	Leaves, tops	Infusion	Stimulant, carminative, emmenagogue
Helianthus	Flowers, seeds, leaves	Tincture	Bitter tonic, astringent
Lobelia	Leaves, tops	Fluidextract, tincture	Expectorant in asthma and bronchitis
Malva	Leaves	Infusion, tincture	Demulcent, emollient
Marrubium	Leaves, flowering tops	Infusion	Bitter tonic, expectorant
Mentha	Leaf (herb)	Oil	Carminative, flavoring agent
Nepeta	" "	"	"
Plantago	Seed	Mucilage	Demulcent, emollient, laxative
Portulaca	Herb, seeds	Infusion	Mild diuretic
Prunella	Herb	Infusion	Aromatic, astringent, bitter
Rhamnus	Bark	Fluidextract	Tonic, laxative, purgative
Rhus	Fruit	Infusion, gargle	Astringent, refrigerant
Ricinus	Bean (seed)	Castor oil	Purgative, lubricant
Rumex	Rhizome, roots	Fluidextract	Purgative, laxative, stomachic, tonic
Saponaria	Root	Alcoholic solutions	Detergent, discutient
Senecio	Plant (herb)	Fluidextract	Mild astringent, counterirritant, emmenagogue
Styrax	Exudation	Compound tincture	Antiseptic, expectorant
Tamarix	Exudation	Infusion	Laxative
Verbascum	Leaves	Fluidextract	Demulcent, emollient

[1] The therapeutic classes of drugs mentioned in this article represent agents used for the following purposes, according to Youngken's "Textbook of Pharmacognosy" or the "New Standard Dictionary" [Ed.]:

Alterative: to change gradually the nutritive processes and bodily habits to a normal state.
Analgesic: to allay pain by depressing the sensory nerve centers.
Anodyne: to produce relief from pain by action on the sensory nervous system.
Anthelmintic: to expel or kill intestinal worms.
Antiperiodic: to modify or prevent return of malarial fever.
Antiseptic: to inhibit, check the growth of, or kill microorganisms on living tissue.
Astringent: to shrink, blanche, wrinkle or harden tissue, diminish secretions and exudates, and coagulate blood.
Carminative: to expel gas and relieve colic.
Cholagogue: to stimulate emptying of the gall bladder and flow of bile into the duodenum.
Condiment: to season or give relish to food.
Corrective: to correct or render more pleasant the action of other remedies, especially purgatives.
Counterirritant: to cause irritation of the part to which it is applied and to draw blood away from a deep seated area.
Demulcent: to soothe and protect mucous membranes.
Depressant: to lessen functional activity.
Detergent: to cleanse morbid parts, as granulating wounds and ulcers.
Diaphoretic: to increase perspiration.
Discutient: to scatter swellings.
Diuretic: to increase flow of urine.
Emmenagogue: to reestablish or increase menstrual flow.
Emollient: to soften and protect the skin.
Expectorant: to cause expulsion of mucous from the respiratory tract.
Galactagogue: to increase lacteal secretion.
Narcotic: to relieve distress and induce sleep.
Refrigerant: to allay thirst and give a sensation of coolness.
Rubefacient: to produce mild irritation accompanied by reddening when applied to the skin.
Sedative: to allay excitement and soothe the system.
Stimulant: to increase functional activity.
Stomachic: to stimulate appetite and gastric secretion.
Taenifuge: to expel tapeworms.
Tonic: to stimulate restoration of tone to muscle tissue.

Drug Plants Under Cultivation on the Pacific Coast

While this article is concerned primarily with the wild sources of medicinal plants in the area covered, a brief account is called for with respect to the attempts so far to bring these plants under cultivation as the beginning of an American crude drug industry.

The importance of the development and the future outlook of such an industry in the region depend to a great extent upon economic conditions in this post-war period. The war has had its influence in stimulating interest in developing native plant resources, and has inspired experimentation with introduced plants from foreign countries. As a rule, these undertakings have been sponsored by or fostered through Experiment Stations, Universities or Colleges, or through cooperative research with the manufacturing industry or the Government. The projects are restricted to tested localities, where some have progressed into thriving undertakings, and they may be briefly surveyed as follows.

In California drug and condiment production has been largely sponsored by the California State Department of Education, the Agricultural College and the California Polytechnic School of San Luis Obispo. The existing condiment crops of the State are mustard, caraway, marjoram, poppy, sage, paprika, sweet basil, thyme, rosemary and summer savory. They are being grown on several thousand acres, and the plantings will probably increase as long as favorable prices prevail. Some other plants, *e.g.*, senna and licorice, have undergone extensive experimentation in southern California. Also, small experimental plots of anise, dill, fennel, coriander, celery, cumin and certain of the mints have been laid out. During the war period approximately 125 acres of pyrethrum were under cultivation.

Commercial development of more native and introduced plants should be worthy of consideration. For instance, eucalyptus, an early introduction to create windbreaks, could undoubtedly be utilized for oil of eucalyptus production, and the castor plant, a horticultural introduction and the source of castor oil, should offer promising adventure for the agriculturist. The drug agar is being commercially obtained from seaweeds and has already become the basis of an industry of considerable size.

Among native wild medicinal plants in the Northwest worthy of attention are cascara, scotchbroom, digitalis, berberis, juniper and ergot, found growing on the range lands of southeastern Oregon. The latest statistics of commercial plantlings of medicinal and allied crops in the State, showing approximate State totals in acreage, are as follows:

Artemisia	20	Ginseng	25
Belladonna	10	Goldenseal	25
Caraway	5	Lavender	1
Cascara	20	Mustard	3000
Coriander	10	Peppermint	4500
Dill	1100	Pyrethrum	60
Flaxseed	2000	Sage	13

In the State of Washington extensive ginseng and goldenseal plantings have been developed, particularly in the Skagit River valley, and production of cascara has also been studied.

Commercial development of the native plant resources in the Pacific Northwest is, however, still in its infancy, but nature has so splendidly prepared the foundation that the region could develop a promising future industry in the production of crude drugs.

Seaweed Resources of North America and Their Utilization[1]

From the coasts of Nova Scotia, Maine, Massachusetts, North Carolina, California and Lower California, seaweeds are harvested that yield agar, algin, carrageenin and iridophycin for industrial use.

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Introduction

For ages, before the advent of white men, the American Indians on the Pacific Coast gathered seaweed for food, and since the latter part of the last century, the Chinese residents in California have also regularly harvested them for the same purpose. On the Massachusetts coast, the collecting of Irish moss has been an established industry for over a century, and for many years East Coast dulse has been sporadically on sale in the markets of Boston, Philadelphia and New York. Utilization of the seaweed resources of North America, therefore, is not a wholly recent matter, but until lately the harvesting and utilization of these marine plants in America were of a rather primitive and sporadic nature. No concerted effort was made to exploit them on an industrial scale, and it took one World War after another to place American seaweed industries on a firm industrial footing. These industries and the natural supplies of seaweeds upon which they are founded, as well as the utilization of those resources, are discussed in this article.

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America's Seaweed Industries

Potash, Acetone, Kelpchar, Iodine.

Shortly before and during World War I there was a serious shortage of potash in the United States, since the supply of this chemical, so vitally important in modern scientific agriculture, at that time came entirely from Germany. Several domestic sources of potash were soon developed, however, through the concerted efforts of the United States Government and of private industry. One of these sources was the California seaweed known as the "giant kelp" (*Macrocystis pyrifera* (Turn.) Ag.). For the duration of World War I, this kelp remained second only to natural brines as a source of American potash. Through a unique fermentation process, acetone and calcium acetate for the manufacture of smokeless powder were also derived from *Macrocystis*. Two other valuable chemical products, iodine and a bleaching carbon known as "kelpchar", were also obtained.

The Pacific kelp industry thus prospered for a few years, with as many as ten factories engaged in the production of potash, acetone, kelpchar and iodine from the California giant kelp. The kelp factory of the Hercules Powder

Company alone handled as much as 24,-000 tons of fresh kelp per month. Mechanical harvesters were devised for cutting the kelp, and production of potash and other chemicals was a feat of modern chemical engineering. Thus, under the stimulus of war, utilization of kelp became well established as a modern industry within two or three years. This potash-from-kelp industry was, however, short-lived, and immediately upon cessation of hostilities, all the kelp factories suspended operation. Since then the American potash-from-kelp industry has not been revived; most probably it will never return, since potash, iodine and acetone can now be obtained more cheaply from sources other than seaweeds.

Algin. The Pacific kelp industry, however, came back in other forms in the late 1930's and is now engaged principally in the production of algin. This is a valuable colloidal substance occurring in many brown algae, especially kelps, and is extensively employed in modern food and other industries in America. In recent years the common Atlantic kelps, *Laminaria digitata* Lamour (horsetail kelp) and *L. saccharina* (L.) Lamour (broadleaf kelp), have also been utilized in the manufacture of algin, and today the annual production of algin in America is estimated at two to three million pounds.

Agar. In the recent war there was no longer a shortage of potash or acetone. There was, however, a shortage of another important material, agar, which is vitally needed in public health work. Agar is derived from red seaweeds, chiefly from members of the genus *Gelidium.* Most of it came from Japan prior to the outbreak of war in the Pacific. Although it has been manufactured in the United States since 1919, domestic agar production amounted to only a small percentage of the total American consumption. Until the outbreak of the war, America's agar industry was not successful, principally because of keen Japanese competition and of the high cost of production. The industry greatly expanded, however, during World War II, and there were five factories engaged in producing this vital product during the war. Production at its peak reached 165,954 pounds in one year. At present, however, only three concerns are still active in processing agar. The seaweeds used are agarweed, *Gelidium cartilagineum* (L.) Gaill. from California and Baja California, Mexico, on the Pacific Coast, and *Gracilaria confervoides* (L.) Grev. from Beaufort, North Carolina, on the Atlantic. Other species of *Gelidium, e.g., G. arborescens* Gard. and *G. nudifrons* Gard., are employed indiscriminately with the agarweed in agar manufacture. On the Atlantic Coast *Gracilaria foliifera* (Forssk.) Borgs. is similarly used.

Carrageenin. Although the Irish moss industry may claim to be the oldest seeweed industry in America, it is only in recent years that it has been established as a modern industry. Formerly the industry amounted mainly to harvesting and preparing the seaweed *Chondrus crispus* (L.) Stackh. and selling it as a crudely cured and partially bleached "moss". The buyer had to extract the colloid carrageenin by boiling the seaweed in water and straining the solution through cheese cloth. In the late 1930's the industry started to produce carrageenin in the form of a purified dry powder, but production in large quantities was not achieved until the last few years. At present at least four firms are engaged in producing this product and about half a million pounds were prepared in 1945. The 1946 production was expected to reach 800,000 pounds. The "moss" is collected and cured mainly in Massachusetts, Maine and the Canadian Maritime Provinces, and the dried black or bleached "moss" is sent

to Scituate, Mass., Passaic, N. J., or Chicago, Ill., for the extraction and preparation of carrageenin.

Iridophycin. Production of the seaweed colloids or phycocolloids—algin, agar, carrageenin—constitute the three principal seaweed industries in America. Since 1945 one firm has been engaged in the production of a fourth phycocolloid, iridophycin, from *Iridophycus flaccidum* Setch. & Gard. and *I. splendens* Setch & Gard. which are harvested from the California and Oregon coasts. The most important non-colloid product is kelp meal which is either made into kelp tablets for human consumption or mixed with alfalfa and other substances into animal feeds. The California giant kelp, *Macrocystis pyrifera*, and the bladder kelp, *Nereocystis Luetkeana* (Mert.) Post. & Rupr., are both used for this purpose.

Food. During World War II, the leafy parts of the bladder kelp were harvested and dried to serve for food among Oriental residents, especially the Japanese in relocation centers, as a substitute for the Japanese kombu, *Laminaria japonica* Aresch., then unavailable because of the war. Both laver and dulse are still being harvested for human consumption.

Figure 1 is a systematic arrangement of the useful American seaweeds and their products in recent years.

America's Seaweed Resources

America's resources of useful seaweeds may be grouped, as indicated in the accompanying diagram, into kelps, agarophytes, carrageens, and other red seaweeds.

Kelps. The most valuable seaweed resource in America is undoubtedly the great abundance of kelps. It is not inappropriate, therefore, to remark on the origin and usage of the term "kelp". In the early part of the eighteenth century it was discovered in Scotland, at a time when there was a great demand for soda ash in the manufacture of soap and glass, that if seaweeds were burned their ash

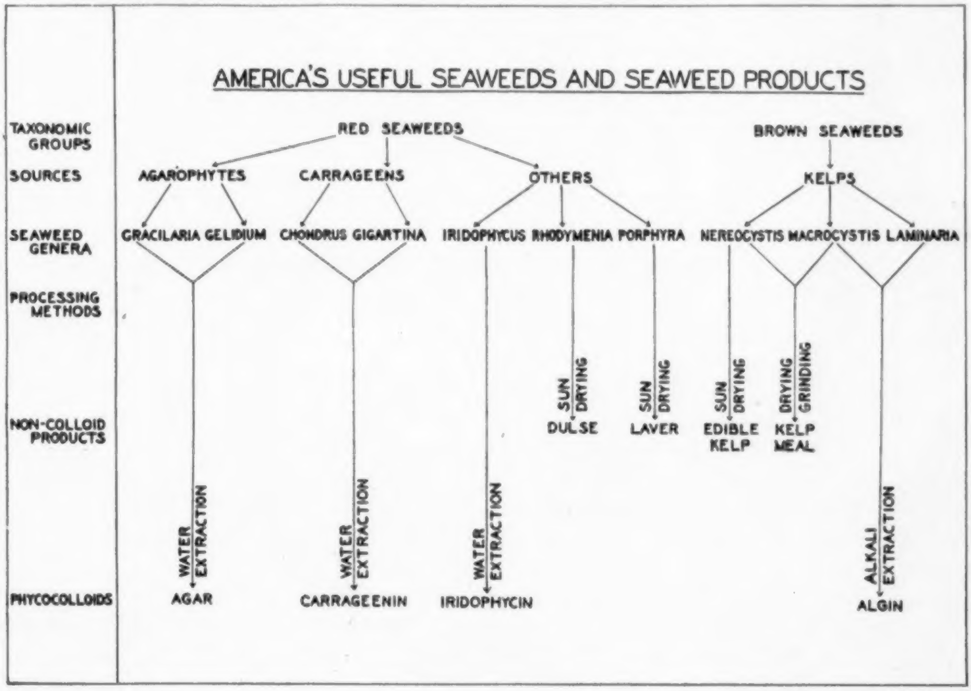

Fig. 1.

was a good source of soda. A seaweed-ash industry was thus born in Scotland and Ireland which was lucrative and important from about 1720 to 1830. To apply to the then valuable seaweed ash, a word of unknown origin, "kelp" was used. In the British Isles the meaning of this word has remained unchanged. The first application of the word to seaweeds themselves, rather than to the ash, appears to have been to an edible New Zealand seaweed called "Bull Kelp" which "has a thick stem, and flat oval-shaped leaf, and is about the thickness of sole-leather". Later this kelp was identified with *Laminaria potatorum* Lamour, a synonym of *Durvillea antarctica* (Cham.) Hariot. When the word "kelp" became known in America in the latter part of the last century, it was applied to certain large brown seaweeds, and *Nereocystis Luetkeana* of the Pacific Coast became "giant kelp", which term was later also applied to *Macrocystis pyrifera* and two others. Eventually they were merely called "kelp". As it is used among botanists nowadays, "kelp" refers to all members of the brown algal order Laminariales with large, flat, leaf-like fronds, although occasionally one finds the word loosely and erroneously used in application to seaweeds generally.

Four species of kelp are utilized in America, two giant kelps on the Pacific and two smaller kelps on the Atlantic seaboard. Among them the most important is undoubtedly the California giant kelp, *Macrocystis pyrifera*.

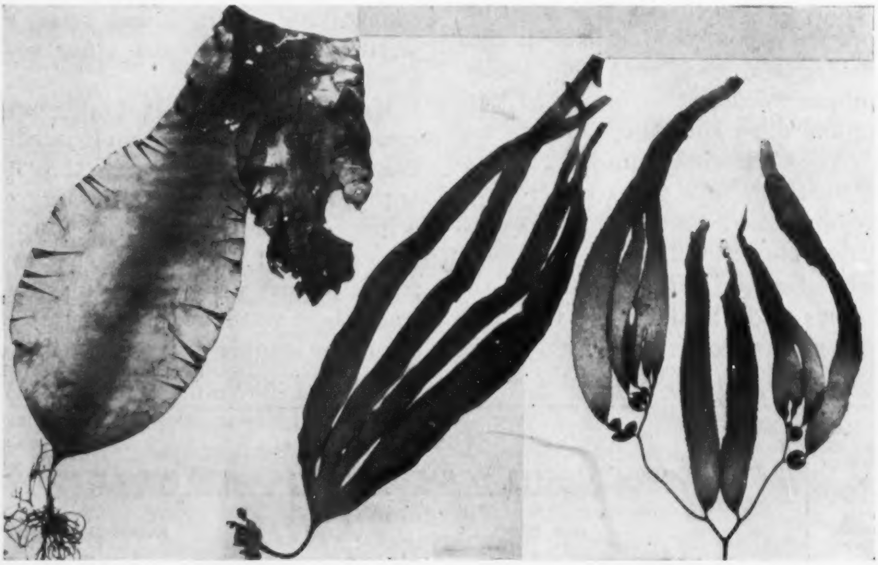

FIG. 2. Three American kelps of commercial importance. The broadleaf kelp (*Laminaria saccharina*) and the horsetail kelp (*L. digitata*), at the left and center, are both found along the East Coast, available in commercial quantities north of Cape Cod. At the right is a very young plant of the California giant kelp (*Macrocystis pyrifera*) which forms extensive beds from Cedros Island, Mexico, to Point Conception, California. These three kelps are the American sources of algin, used in a variety of ways described in this article. (*Courtesy of Dr. William Randolph Taylor, of the Scientific Monthly and of the Journal of The New York Botanical Garden.*)

Macrocystis. While there are two species of *Macrocystis* on the American Pacific Coast, *M. pyrifera* is the only one commercially utilized in the algin and kelp meal industries, the other species being available only in small quantities. The former is a truly "giant" kelp, and is undoubtedly the largest seaweed

known. While it has been reported by earlier authors to attain the enormous length of 1,000 feet, on the American Pacific Coast the largest plant ever actually measured and recorded was about 140 feet long. A perennial plant, it grows on rocky bottoms free from shifting sand, 25 to 90 feet below the water surface. It grows best in places where there is a continuous swell; and where environmental conditions are favorable, it forms extensive beds from a few hundred yards to two or three miles wide and several miles long. From Cedros Island, Baja California, in the south, to Point Conception, California, in the north, it is practically the only constituent of the kelp beds. Northward it is a minor component of the beds along the coast from central California to southeastern Alaska.

This giant kelp attaches itself to rocks by means of a large conical holdfast, composed of long, densely compacted, branched haptera. It has a stipe which is usually four or five times forked near the base. The branches of the stipe bear blades unilaterally at regular intervals. New lateral blades are formed by asymmetrical splitting of the terminal blade from base to apex. Each mature lateral blade has a short stalk, and a subglobose to spindle-shaped basal pneumatocyst or air bladder. The blade is lanceolate, undivided, up to 80 cm. long and 40 cm. broad, and has an irregularly corrugated surface with denticulate margins.

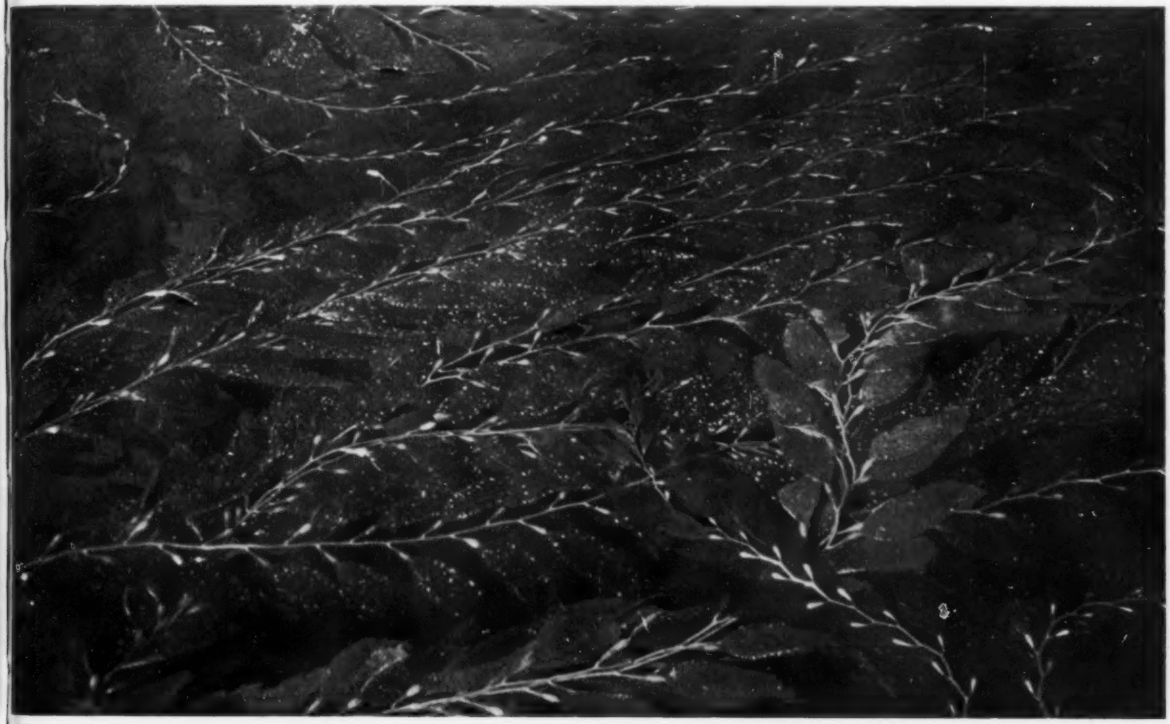

FIG. 3. Fronds of the California giant kelp (*Macrocystis pyrifera*) floating on water near Laguna Beach, Cal. (*Courtesy of the U. S. Fish & Wildlife Service and of the Journal of The New York Botanical Garden.*)

In the early days of the American kelp industry macrocystis was gathered from the beach where it was washed ashore, or whole clumps destructively pulled up by means of a cable and hoist; or the fronds

were dragged into a skiff with a hook and cut off with a long knife. All these methods required too much labor and were too inefficient for an American industry to be successful. The mechanical harvester which was later devised solved the labor problem and contributed greatly to the success of the Pacific kelp industry.

A mechanical kelp harvester is a motor-run barge equipped with a modified mowing machine, having a horizontal cutting blade at a depth of about four feet and an endless chain elevator which hoists the kelp on board. The harvesting machine is placed in the bow, with the blade cutting directly ahead of the boat. The

FIG. 4. A kelp harvester of the Hercules Powder Company during World War I. (*Courtesy of the Hercules Powder Company.*)

knife is considerably shorter than the beam of the boat, and is generally 10 to 20 feet wide. The elevator is as broad as the swath. Its lower sprocket wheels are immediately back of the cutter bar, and it is driven at rather high speed, so as to pick up the cut kelp before the waves wash it away. A knife at each side of the elevator, and parallel with it, serves as an edging device to cut the kelp clear at the sides. Such a barge can harvest and carry as much as 300 tons in a single load. Harvesting is carried out in calm weather throughout the year. By cutting the beds in rotation, they can be periodically worked, and a sustained yield is assured.

There are no figures available as to the cost of harvesting the giant kelp, since kelp firms operate their own harvesters and do not purchase help from outside sources. Estimates have been placed between two and five dollars per ton of fresh kelp.

Nereocystis. Of the three other giant kelps, *Nereocystis Luetkeana*, the bladder kelp, also known as the "ribbon kelp", is the only one commercially exploited, although to a much less extent than macrocystis. Although an annual, nereocystis grows to gigantic size within a year, plants over 100 feet long being reported, and forms extensive beds like those of macrocystis. The plant has a hemispherical holdfast consisting of densely compacted branched haptera, and an elongated, subcylindrical stipe, gradually broadening upward and terminating in a subglobose pneumatocyst, the apex of which bears four short flattened four or five times dichotomous branches. These bear 32 to 64 long linear undivided smooth blades which may be over ten feet long and one foot broad.

It has been reported that mechanical technique was used in cutting the nereocystis in the Puget Sound area during World War I. Utilization of the bladder kelp, however, has never been on a large scale, and it is highly doubtful that mechanical harvesting could be carried out economically on small scale operations. Along the central California coast, at Monterey and other nearby regions, the rather ancient method of reaping the kelp by hand with large scythes from scows has been used.

During World War II, large quantities of this kelp were harvested for food as substitute for the Japanese kombu (*Laminaria japonica*), only the leafy parts of the fronds being utilized. The war-time production was about 100 tons of the dried nereocystis per annum. Being thinner and less tasty than the Japanese kombus, the bladder kelp is con-

sidered inferior in quality, and its production was terminated shortly after cessation of hostilities in the Pacific. Dried leafy parts of the bladder kelp cost about $400 per ton.

Pacific Kelp Beds. Thanks to the extensive surveys of the kelp beds along the Pacific Coast of North America conducted by the United States Department of Agriculture in the years 1911–1913, we have a fairly good knowledge of their approximate size, location and productivity at that time. The following table summarizes the result of this investigation:

Conception the predominant constituent of kelp beds was *Nereocystis,* with *Macrocystis* and *Alaria* in minor quantities. Survey of the coast along southeastern Alaska was incomplete and covered perhaps less than half of the region. Cameron therefore added an additional estimate to allow for the region not surveyed.

The foregoing 1911–1913 estimate of kelp supplies in the Pacific beds was undoubtedly much too high, for later harvestings yielded less than 10% of the estimated amount. There are plentiful kelps growing in places where, for one

TABLE I

AREA AND PRODUCTIVITY OF PACIFIC KELP BEDS
(Compiled from data of Cameron, Crandall, Frye and Rigg, 1915)

Region	Area sq. miles	Fresh kelp tons	Constituents of the beds, %				
			Macrocystis	*Mac. + Ner.*	*Nereocystis*	*Ner. + Ala.*	*Alaria*
1. Cedros Island, Mexico, to San Diego, Calif.	91.36	16,979,800	100	......	......	......	......
2. San Diego to Point Conception	97.92	18,195,300	100	......	......	......	......
3. Point Conception to Cape Flattery	36.24	4,377,400	17	7	76	......	......
4. Puget Sound	5.00	520,000	Minor	......	Major	......	......
5. Southeast Alaska	70.78	7,833,000	18	......	78	......	4
6. Southeast Alaska (estimated)	70.78	7,833,000	......	......	......	......	......
7. Western Alaska	17.86	3,567,000	......	......	55	33	12
Total	389.94	59,305,500					

It is to be noted that this survey included three kinds of giant kelp, namely, *Macrocystis pyrifera*, *Nereocystis Luetkeana* and *Alaria fistulosa* Post. & Rupr. In the first and second regions the kelp beds consisted practically entirely of macrocystis, with some *Pelagophycus porra* (Leman) Setch. the elk kelp, in scattered groups along the outer edge of the beds. *Macrocystis* being a perennial plant, determination of the yield of such beds was based on two cuttings per annum. North of Point

reason or another, it is not economically practical to harvest them. Actual cutting of macrocystis in the years 1916–1920, between San Diego and Point Conception, showed the highest annual yield at 394,974 tons in 1917, which amount was slightly over 2% of the estimate.

Wohnus in 1942 made a careful survey of the three kelp beds in the region between La Jolla and San Diego, California. He found a considerable decrease in area since the 1911 and 1934 surveys (Table II).

The numbering of the beds is based on the official kelp chart of the California State Fish and Game Commission. According to Wohnus (personal communication), the 1911 figures were obtained by measuring the areas of the kelp beds on the maps prepared by Crandall. The 1934 data were based on the Coast have not yet regained the extensive growth described in previous surveys, there are a few regions in which kelp is now growing where it had not been reported previously. Wohnus believed that, with care and proper regulation, the supply of kelp can be maintained and the present yield increased.

FIG. 5. Fronds of the bull or bladder kelp (*Nereocystis Luetkeana*) floating on the waters of Puget Sound. (*Courtesy of Dr. Robert H. Tschudy and of the Journal of The New York Botanical Garden.*)

and Geodetic Survey map, in which the outlines of these California coastal kelp beds were indicated. Concerning the general condition of the beds, Wohnus stated that there were definite signs of improvement. Although in some areas, such as beds No. 2 and 3, the plants

Kelp Production in California. Tabulated monthly records of the actual kelp production in California during and immediately after World War I have been published. Large scale harvesting started in August, 1916 and stopped in November, 1918. Commercial cutting of

TABLE II

CHANGES IN AREAS IN STATUTE MILES OF THREE KELP BEDS IN THE LA JOLLA–SAN DIEGO REGION

Bed No.	Year	Area sq. statute miles	Change over 1911		Change over 1934		Remarks
			Actual area change	Per cent of change	Actual area change	Per cent of change	
2	1911	1.4					Heavy
	1934	0.88	−0.52	−37			Scattered
	1941	0.50	−0.90	−66	−0.38	−43	Very thin
3	1911	4.08					Heavy
	1934	2.77	−1.31	−32			....
	1941	2.14	−1.94	−47.5	−0.63	−22.7	Thin
4	1911	2.1					Heavy
	1934	2.6	+0.5	+23.8			....
	1941	2.5	+0.4	+19	−0.1	−3.8	Medium

the kelp, however, was continued, although on a much smaller scale, for two or three years after the war until all the kelp factories were shut down. The largest annual production was 394,974 tons in 1917.

It should be noted that the production in 1918, namely, 390,863 tons, was only for the period January through October. If kelp was harvested in November and December, proportionally the 1918 production would reach a record high of about 500,000 tons. Since cuttings were made in places more accessible and closer to the operating plants, there were undoubtedly similar quantities of kelps in less accessible places which were not harvested. It is not unreasonable to believe, therefore, that the coastal region between San Diego and Point Conception, with judicial cutting, could produce as much as a million tons per annum, which is slightly more than 5% of the 18,195,300 tons estimated for this region in 1911–1913. On the same basis, the productivity of the Pacific kelp beds may be placed at about three million tons per annum.

TABLE III

MONTHLY RECORDS OF CALIFORNIA KELP PRODUCTION, 1916–1920, IN TONS OF FRESH KELPS

Month	1916	1917	1918	1919	1920
January	1,424	37,100	43,118	1,150	2,136
February	3,310	33,733	24,429	930	1,770
March	3,310	29,995	41,916	1,999	1,970
April	3,310	24,249	43,009	2,101	1,508
May	3,310	41,711	45,838	1,771	2,432
June	3,310	41,631	35,022	877	2,136
July	3,310	24,903	42,084	1,380	2,290
August	37,784	25,612	50,507	1,565	1,955
September	19,135	32,739	35,395	587	2,365
October	10,720	35,522	33,780	1,791	1,950
November	17,757	36,582	....	1,184	2,668
December	27,857	31,197	....	1,315	2,284
Total	154,537	394,874	390,863	16,613	25,374

Through the kindness of the California Division of Fish and Game, the writer has obtained monthly records of kelps actually harvested in the last six years by the kelp industry. Cutting of macrocystis is conducted between San Diego and Point Conception. It is to be noted that the present annual kelp harvest averages about 56,000 tons, or only slightly more than one tenth of that during the peak production years, 1917 and 1918.

Regulations. In California persons engaged in harvesting kelp or other aquatic plants for commercial purposes are required to have a license which costs them ten dollars per year. In addition, there is a privilege tax on kelps and other seaweeds at five cents per ton of wet weights. One may also lease kelp

FIG. 6. Bull or bladder kelp (*Nereocystis Luetkeana*). When dried and ground it is used for making kelp pills for humans and kelp meal for livestock rations. (*Courtesy of Dr. Robert H. Tschudy and of the Journal of The New York Botanical Garden.*)

beds, not exceeding 25 square miles in area, for a period of 15 years, upon payment of $40.00 per square mile. Kelps harvested from leased beds are taxed at three cents per ton of wet weights, in addition to the license and leasing fees.

Laminaria. Two species of kelps are utilized on the Atlantic Coast of North America. They are the broadleaf kelp, *Laminaria saccharina*, and the horsetail kelp, *L. digitata.* Both have a firm holdfast, a distinct stipe and a large broad blade, simple in the former and digitately divided in the latter species. The blades are smooth and yellowish to olive brown and may reach ten feet or more in length. They grow on sublittoral rocks, and occur in commercial quantities from Cape Cod northward. Most of the Atlantic kelps used in the algin industry come from the waters off Nova Scotia. Harvesting is effected with a grapple hauled at a depth of 12 to 15 feet from a power boat, and to a lesser extent by hand dragging or sickling from a dory. The harvesting season extends from June to December.

Laminarias do not float on the surface of the water. Kelp beds consisting of them are therefore not as readily surveyed as the giant kelp beds of the Pacific Coast. There are no data as to the supply and harvest of kelps on the Atlantic Coast. We may obtain some idea, however, as to the amount of kelp harvested on the Atlantic Coast, on the basis of actual alginate production, which amounted to about 300,000 pounds in 1944. Since the two laminarias contain on the average about 4% of algin, on the basis of fresh weight, the minimum annual production of fresh kelp should be at least 4,000 tons, or slightly less than 10% of the current Pacific Coast production. There are reasons to believe, however, that the potential kelp resources of the Atlantic Coast are many times the above estimate.

TABLE IV

MONTHLY RECORDS OF CALIFORNIA KELP PRODUCTION, 1940–1945, IN TONS OF FRESH KELPS

Month	1940	1941	1942	1943	1944	1945
January	1,671	4,417	5,672	3,868	4,256	3,866
February	2,511	2,184	5,967	2,928	2,768	2,990
March	3,231	2,191	6,514	3,683	4,655	3,090
April	3,200	3,281	4,078	4,136	4,519	4,372
May	5,007	4,112	5,506	4,920	5,007	5,340
June	6,283	5,281	5,311	5,846	5,963	6,454
July	6,390	7,274	5,715	5,371	5,410	5,882
August	6,142	5,465	5,726	3,240	5,509	5,005
September	5,426	3,337	5,127	2,323	3,667	5,399
October	7,189	6,733	4,417	3,261	5,393	5,863
November	7,063	5,810	3,814	3,978	4,352	6,584
December	4,897	5,632	4,255	4,414	1,536	4,338
Total	59,010	55,717	62,102	47,968	53,035	59,183

There are several species of *Laminaria* which abound on the Pacific Coast, but to date, none has been utilized. Commercial utilization of laminarias, in general, is handicapped by the necessity of harvesting by manual labor, which increases tremendously the cost of the raw material for the industry. If mechanical means could be devised to gather them economically, there is no doubt that the laminaria resources of America could be more thoroughly exploited.

Agarophytes. The two principal agarophytes in America are *Gelidium*

cartilagineum and *Gracilaria confervoides.* The term "agarophyte", originally spelled "agarphyte", was coined by the writer in 1944 to designate red algae utilized in the manufacture of agar, so as to avoid using the term "agar" to apply to both the raw material and the dried extract. Formerly *Gelidium* was the only group used commercially in the American agar industry, but when the discovery of a rich *Gracilaria* resource in the Beaufort, N. C., region was made by Humm in 1942, a new agar industry based on *Gracilaria confervoides* was born on the East Coast.

Gelidium. The "agarweed" of commerce is the maroon or purplish-red Californian *Gelidium cartilagineum* var. *robustum* Gard. This alga is found in commercially harvestable quantities in southern California and Baja California, Mexico, between Point Conception in the north and Magdalena Bay in the south. Although it grows very well in the Monterey region along the central California coast, its growth there is generally sparse and rarely dense enough to warrant commercial gathering.

This plant has a characteristically naked stipe, sometimes as much as seven cm. in length. It is repeatedly pinnately branched and the young branches are typically geniculate, *i.e.*, the outer ends are almost parallel with branches from which they arise. Later the branches, usually opposite but sometimes alternate, straighten and stand at about a 45° angle. The entire plant reminds one of the frond of a fern and is hence sometimes known as "sea-fern". It grows in tufts and attaches itself firmly to the rocky substratum by numerous rhizoidal filaments. While it has been reported by professional harvesters to reach a height of more than five feet, the largest specimens seen by the writer were about four feet tall. The plant is generally considered to be harvestable when one and a half to two feet in height.

Gelidium cartilagineum is typically a sublittoral plant, growing from the lowest spring tide level to a depth of 40 to 50 feet. It does not grow in extensive beds, as does *Macrocystis pyrifera*, but is generally found in comparatively small concentrations, localized on the

FIG. 7. Principal agarophytes used in the American agar industry, the California agarweed (*Gelidium cartilagineum* var. *robustum*, right) and East Coast agarweed (*Gracilaria confervoides*, left). (*Courtesy of U. S. Fish and Wildlife Service and of the Journal of The New York Botanical Garden.*)

tops or at the edges of rocks or boulders in places where the tidal current is strong. Consequently mechanical harvesters for it have not yet been successfully devised, and harvesting has to be effected by raking or by diving and hand-picking. Raking is, however, rarely employed, and is possible only when the water is extremely calm and rather shallow. Before the war some Japanese harvesters who were experienced in raking seaweeds gathered tons of this agarophyte from the San Pedro breakwater. The majority of harvesters dive and hand-pick the seaweed, and, with a few exceptions, use a complete diving rig.

An agar diving boat is generally a small fishing boat about 30 feet long, equipped with air compressor and heavy rubber hose to supply air for the diver while he is working under water. The crew consists of three persons, a boat operator, a diver and a life-line tender. The last mentioned takes care of the air-line and the life-line; the latter is a rope with one end tied around the waist of the diver and the other end held tightly by the tender. By signals, as indicated by the number of pulls by the diver on the rope, the line tender knows whether to lift up the harvest or to haul up the diver. While generally there is a single trained diver in a boat, there may be two. In this case they alternate as life-line tender and diver. This system has the advantage of better working efficiency and increases the harvest per diving boat by as much as 50%.

While the general location of commercial quantities of agarweed is known to the divers, they have to hunt for the particular spots where plentiful supplies of the plant are available. Generally speaking, *Gelidium* growths are readily noticeable by experienced divers, because of the presence of the bryozoan *Membranipora* on the older parts of the plants. Experienced agar harvesters have also claimed that wherever one finds the "goldfish" garibaldi (*Hypsypops rubicunda*), one may expect to find good growths of *Gelidium* in the near vicinity.

Since *Gelidium* grows most abundantly around the edges and on the slanting surfaces of rocks and boulders in places where the water is generally turbulent and the water movement fast, the agar diver usually has to crawl from one rock to another, and occasionally grasps the large kelps for support. With one hand he carries a basket made of small ropes; with the other he pulls a bush of the agarophyte from the rocks and puts it into the basket. When he has filled the basket he ties it to his life-line and pulls the rope twice. Upon receiving the signal, the life-line tender hauls up the basketful of agarweed, weighing between 60 and 75 pounds, and lowers an empty one to the diver. When the harvester is tired, he pulls the rope three times, and the vigilant life-line tender quickly pulls him up.

An experienced diver generally works continuously for one to two hours under water. Then he comes up for a short rest. He may dive two or three times a day, working under water for four or five hours. The diving boat usually goes out in the early morning, since the ocean is as a rule quieter in the morning than in the late afternoon. The actual diving hours average about four per day with a single diver and six with two divers on the same boat.

The quantity of agarweed that a diver can gather per trip depends upon his experience, the condition of the sea and the abundance of the *Gelidium* growths. Under the best conditions a diver may pull as much as one and a half tons of fresh agarweed per diving day. For an average diver working under the usual conditions in southern California, however, a harvest of 1,500 pounds of fresh weed per day is considered very satisfactory.

The agarweed thus harvested is spread

on level ground and dried in the sun, but is not washed or bleached, as is done with the Japanese tengusa. In California fresh agarweed is worth about $80, and dry about $350, per ton.

On the Pacific Coast, besides *Gelidium cartilagineum*, other species of *Gelidium* have also been used occasionally in the industry. The name "hair-agar" is generally applied by the agar divers to do not grow as luxuriantly as the agarweed, they are only occasionally gathered. In the drying field and in the factory they are generally mixed indiscriminately with the agarweed.

Two other species, *Gelidium densum* Gard. and *G. ramuliferum* Gard., have also been reported to be used by the California agar manufacturers, though apparently not in recent years, for the

FIG. 8. Drying agarweed (*Gelidium cartilagineum* var. *robustum*) near Newport Beach, Calif. (*Courtesy of U. S. Fish and Wildlife Service.*)

Gelidium nudifrons and sometimes also to *Gelidium arborescens*. These have thin and hair-like filaments, hence the vernacular name. They grow in deep waters, as does the agarweed, although in somewhat more sheltered places. They form bushes about three feet in height, and have to be harvested by diving and hand-picking. While they produce a slightly inferior agar, they are considered satisfactory agar sources. As they writer has never found any in the California agar firms. While there are several species of *Gelidium* on the Atlantic Coast, they are all too small for industrial use and not available in commercial quantities.

Agarweed Production. Production of agarweed on the Pacific Coast is rather irregular, since diving is a hazardous and tiresome profession, especially diving for agarweed which has to be pulled

from the rocks. Moreover, in places where the agarweed abounds, abalone is also found in large quantities, and experienced divers generally prefer to take up the more remunerative abalone diving. Furthermore, an agar diver can work only six or seven months a year, since it is not feasible, because of heavy ground swells, to work under sea during the winter and spring months. Consequently in California very few people are willing to take up agar diving as a profession. In Baja California, Mexico, the conditions are somewhat better, as agar diving is comparatively a better job than others there. The agarweed also grows more luxuriantly in the Mexican waters, and harvest per work day is higher than in California.

Monthly records of agarweed harvested in southern California from 1942 through 1944 are available through the kindness of the California Division of Fish and Game and are presented in the following table:

TABLE V

MONTHLY AGARWEED PRODUCTION IN SOUTHERN CALIFORNIA, 1942–44, IN POUNDS, WET WEIGHT

Month	1942	1943	1944
January	....	15,737	1,540
February	....	200	11,861
March	....	21,798	14,114
April	....	....	....
May	10,700	2,453	12,102
June	46,000	10,675	38,869
July	41,000	25,491	106,287
August	29,400	102,880	96,222
September	6,085	21,337	51,515
October	9,243	13,326	125,156
November	30,622	7,462	21,295
December	42,676	....	3,260
Total	215,726	223,359	482,221

The monthly fluctuation of the harvest does not necessarily reflect upon the abundance of the weed in the various months, since the amounts gathered depend mostly upon the number of divers engaged in the work and the number of days when the sea was calm enough for agar diving. If we take the 1944 figure as a more representative one for normal production of agarweed in southern California, it is equivalent to about 240 tons wet weight, about 80 tons dry weight. Of these, about 27% came from the coast between Newport, Laguna and Dana Point, about 70% from Redondo and Point San Vincente, and the remaining from La Jolla and Point Loma, San Diego, based on figures supplied by The American Agar and Chemical Company, the largest agar producer in America.

The agarweed resource of the southern California waters is undoubtedly many times the 80 tons actually produced in 1944, since harvesting was then limited to only a few places readily accessible to diving boats. Wartime restrictions prevented operations in numerous places. Even in places where agarweed was gathered, probably more gelidium was left than was harvested. There are reasons to believe that southern California, if thoroughly but judiciously exploited, could yield upwards of 500 tons of dry agarweed per anum.

The majority of gelidium used in industry comes from Baja California, Mexico. While data of the Mexican production are not available to the writer at this moment, they can be easily calculated from the actual agar production and from the amount of agarweed harvested in California. The 1943 production of agar in California was 165,954 pounds, and on the average yield of 18 pounds of agar per 100 pounds of dry agarweed, the amount of raw material required will amount to 920,000 pounds or about 460 tons. Since southern California produced in 1943 only 223,359 pounds of wet gelidium, equivalent to about 40 tons, dry weight, the Mexican production should be about 420 tons, or about ten times the California production.

Gracilaria. Of the numerous species of *Gracilaria, G. confervoides* is the species most extensively employed in agar manufacture. It is, however, only in recent years that the value of this species as a commercial source of agar has been duly recognized and well established. It has been used for years in Japan in making agar, but it has always been a secondary source, used merely as a supplementary material. The recent research conducted in America by Humm and in other countries, including Australia and South Africa, has definitely shown that low. The plant is dull purplish-red to purplish, grayish or greenish translucent. It grows best in sheltered bays, especially near river estuaries, where the water is shallow, the bottom sandy to somewhat muddy, and the water movement very sluggish. Under good environmental conditions, in most places, it grows five to six feet long in one season. At Beaufort, N. C., loose pieces of *Gracilaria* have been known to increase ten times in weight within two weeks. At Cherry Point, Vancouver, British Columbia, plants 12 feet long are not uncommon.

FIG. 9. Spreading agarweed (*Gracilaria confervoides*) on wire netting erected a few feet above the water surface for sun drying near Beaufort, N. C.

Gracilaria has its appropriate place in agar manufacture. Extraction of agar from *Gracilaria* has now passed from the experimental stage to large-scale commercial production in Beaufort, North Carolina, as well as in Australia and South Africa.

This agarophyte has a bushy frond attached by a discoid holdfast to stones, pebbles, shells, *etc.* The plant body is repeatedly divided, alternately branched, with numerous lateral proliferations. The branches are cylindrical throughout, 0.5 to 2.0 mm. in diameter, tapering gradually above and more abruptly be-

In places where *Gracilaria confervoides* occurs in commercially harvestable quantities, it generally grows and accumulates in great loose masses. Harvesting gracilaria is therefore a very much simpler matter than harvesting *Gelidium cartilagineum.* It may be collected by forking it into small boats or hand-picked when the tide is low enough. The wet gracilaria may be sent directly to the factory for agar processing, or may be dried in the sun on wire nettings, erected a few feet above water. Humm reported that between August 1, 1943, and January 1, 1944, 1,000 to 1,500 tons

of wet gracilaria were gathered in the vicinity of Beaufort, North Carolina. This was estimated to be equivalent to 150,000 to 200,000 pounds of dry gracilaria, or about 75 to 100 tons.

Gracilaria confervoides is a widely distributed, cosmopolitan seaweed, and grows in sheltered shallow bays where the water temperature is considerably raised by solar radiation. It is found extensively, therefore, along both coasts. In Indian River, Florida, a variety of this species grows luxuriantly, forming large mats on the eastern side of the bay. No quantitative data are available, but apparently the quantity available is much more than that in the Beaufort region, or other places that the writer has investigated. *Gracilaria confervoides* is also abundant along the Gulf of Mexico coasts, although no effort has yet been made to determine its production there.

On the Pacific Coast this species forms beds in San Diego Bay at Chula Vista, California. The productive area is, however, relatively small, and this particular bed is probably able to supply about 100 tons of fresh gracilaria per annum, or about 15 tons, dry weight. Because of the lack of extensive shallow sheltered bays in southern California, the writer was unable to locate any other gracilaria beds besides the one at Chula Vista. This species apparently thrives as far north as the east coast of Vancouver Island, British Columbia, where it grows to over 12 feet in length. Growth is rather sparse, however, and commercial exploitation does not appear to be feasible.

Besides *Gracilaria confervoides*, *G. foliifera* is also utilized in agar manufacture in the Beaufort, N. C., region, but is considered inferior to the former in quality. It generally appears in early summer, just before *Gracilaria confervoides*. On the Pacific Coast, another species, *G. Sjostedtii* Kylin, grows in large quantities on rocks on sandy beaches, and might also be utilized in the industry, if extensive beds could be found.

Carrageens. The name "carrageen" is derived from the coastal town of Carragheen in the Irish Free State, and referred originally to the seaweed *Chondrus crispus*, more popularly known as "Irish moss". The term is now also applied to *Gigartina stellata* (Stackh.) Batters which is commonly harvested together with the Irish moss and used for similar purposes. It has been suggested, therefore, to use the term "carrageen" in a generic sense to include both *Chondrus* and *Gigartina*, and to limit "Irish moss" exclusively to the former.

Irish moss. *Chondrus crispus* is a bushy plant with several blades from a disk-like holdfast, generally 8 to 15 cm. tall, forming loose or often dense clumps. It has a slender compressed stalk which expands sharply into the wedge-shaped base, dividing dichotomously into a flabellate blade. The individual segments vary a good deal, some linear-compressed, some narrow band-like, and some broad-membranous, their breadth varying from 2 to 15 cm. The color of the plant ranges from dark red-purple when shaded or growing in deeper waters, to greenish when growing in shallow places.

Irish moss grows throughout the year on rocks, shells or woodwork in tide pools and in the intertidal regions down to 15 feet or more in depth. The usual method of gathering the "moss" is to hand-pick it when the tide recedes, or to rake it from below the water. In America the harvesting method is essentially the same as that of a hundred or so years ago.

A "moss" harvester does not require much equipment. He needs a 12-foot dory, a pair of oars, a rake, some crude fish oil, an anchor and a creel to carry the harvest from the dory to land. The

rake is the only special equipment needed. It consists of a wooden handle, 15 to 20 feet long, and a steel strap, measuring 12 to 15 inches across and having 24 to 28 teeth. The teeth are six to eight inches long, made from quarter-inch. square steel tapered towards the outer end, and set, usually by electric welding, about one-eighth inch apart. The handle is set at an angle of about 75 degrees to the teeth. In harvesting the "moss", the rake is drawn with the teeth parallel to the bottom along the seaweed bed. The stems of the plant slide between the teeth and are held tightly there. The rake is then lifted and the "moss" pulled out and thrown into the dory. When the water is rough some fish oil is poured on the sea to improve visibility, thus helping the harvester to locate the seaweed beds.

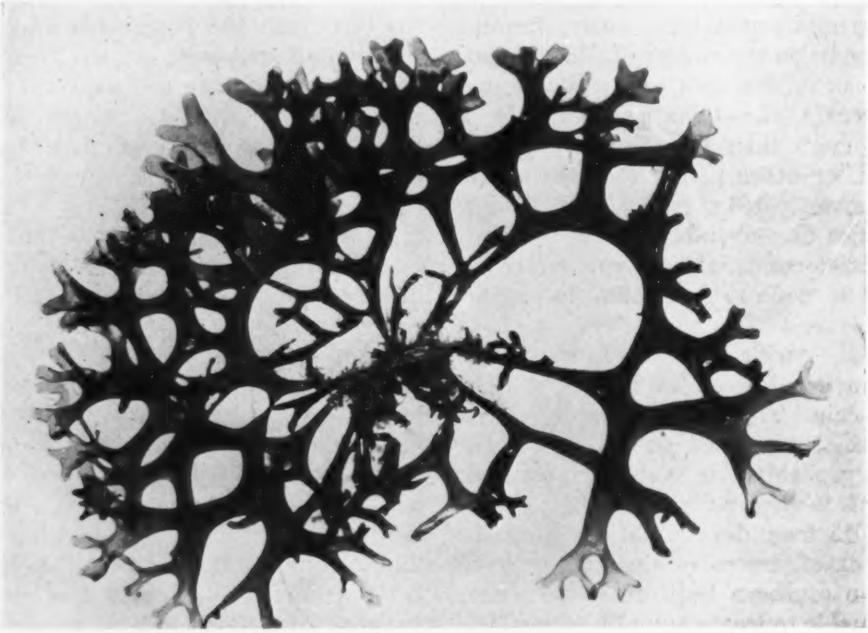

FIG. 10. *Chondrus crispus*, the Irish moss or carrageen of commerce, the collecting of which constitutes the oldest seaweed industry in the United States. For a century it has been harvested and sold, chiefly for making blancmange. Lately, a commercially useful extract, carrageenin, has been prepared from it, to serve as a stabilizer in chocolate milk, salad dressings, soda fountain syrups, cough syrups, tooth paste, hand lotions, and other products. (*Courtesy of Dr. William R. Taylor, of The Scientific Monthly and of the Journal of The New York Botanical Garden.*)

Harvesting is conducted about two hours before and after the lowest tide. An average harvester during this period can gather about 400 pounds of wet Irish moss. Under extremely favorable conditions as much as 1,200 pounds can be harvested by a single person in a day. Upon returning to the shore he packs his harvest in the wooden creel and carries it to the drying fields or sells it immediately to the brokers.

Irish moss should be cleaned and dried as soon as possible to prevent fermentation, which will produce a poor product, and should be thoroughly washed free from shells, stones and the various types of animals accompanying it. Under First Cliff at Scituate, Mass., the operators are equipped with a big tank and two motors for curing the seaweed. One motor controls the continual flow of

water pumped from the ocean which sprays the "moss" in the tank, and the other turns the giant paddles that beat the plant. From the vat the seaweed descends to a picking table of steel mesh that runs as an endless belt. Here the "moss" is separated from the crabs, periwinkles, rock eels, *etc.*, that do not come out in the vat. The cleaned Irish moss is then transported to the drying boards, canvas or wire netting. It is thinly spread, bleached and dried in the sun.

Irish moss is produced in several European countries, especially Ireland, Scotland and France. Before the war most of the carrageen and its extract sold in America came from these three sources. After the war in Europe started, both the United States and Canada accelerated their production which may now exceed the total European output.

On the American Atlantic Coast, although *Chondrus crispus* occurs from New Jersey to Newfoundland, only certain regions have large enough quantities to support commercial harvesting. In the United States, Massachusetts and Maine are the two carrageen-producing states, and Scituate, Mass., is still the center of Irish moss production, which is affording a livelihood for at least 300 local people. Gloucester and Quincy, and to a less extent Lynn and Nahant in the same State, are also producing this seaweed. According to one processor, production of Irish moss in Scituate and nearby regions was expected to reach half a million pounds dry weight in 1946.

Chondrus crispus is reported to be abundant along the entire length of the Maine Coast. Although the Maine Irish moss industry is comparatively young, it is estimated by one processor to have produced two million pounds of the fresh seaweed, or close to 400,000 pounds of the dry plant in 1944. The present annual United States production is estimated by two of the largest producers at about five million pounds of fresh or close to one million pounds of dry Irish moss. Irish moss costs about \$40 per ton when fresh and about \$400 when dried and bleached.

In Canada the greatest quantity comes from Prince Edward Island and the mainland from the Gut of Canso to Malagash and from Richibucto to Point Escuminac, in the southern part of the Gulf of St. Lawrence. Large quantities also come from the outer coast of Nova Scotia, with good producing grounds in Yarmouth County. The annual Canadian production rose from the prewar 10,000 pounds to 261,000 pounds in 1941, and 2,006,000 pounds dry weight in 1942. The 1943 production was only 877,000 pounds, a figure based on shipment records. One authority believed that over 1,200,000 pounds were actually produced in 1943. The smaller production in this particular year was assumed to be due to the excessively large purchase in 1942, so that buyers were very critical about the quality of the product, and refused to take inferior materials. Current annual production is about two million pounds.

Gigartina. Before the last war in Europe, one carrageenin producer in the United States imported annually for several years about 15 tons of the so-called "Portuguese moss". This consisted of three different seaweeds. "Portuguese moss, wiry type" is *Gigartina acicularis* (Wulf.) Lam., and "Portuguese moss, wide-leaf type" is a mixture of *Chondrus crispus* and *Gigartina stellata*. As the "wiry type" is a more important constituent of the "Portuguese moss", the name should be restricted to *Gigartina acicularis*. This gives a colloid similar to, if not identical with, the Irish moss carrageenin. The Portuguese moss colloid, however, gives a much more viscoid solution than that from Irish moss, and is used for certain special purposes.

Although *Gigartina stellata* is almost as abundant as the Irish moss on the

northern European coasts, this species does not appear to be available in sufficient quantities on the American side of the Atlantic to warrant commercial harvesting. Among commercial samples of American Irish moss, *Gigartina* is indeed a rare component. On the Pacific Coast there are several species of *Gigartina*, one of which, *G. corymbifera* Kuetz., occurs along the central and northern California Coast in sufficiently large quantities for commercial exploitation. It contains a colloid of excellent stabilizing power, probably identical with carrageenin from Irish moss. This seaweed is a broadly membranous form with thick and tough blades reaching two to three feet in length. It grows profusely on rocks at or below low tides, and has to be collected during spring low tides. Collecting is not difficult, however, and the writer once gathered about 80 pounds in about 15 minutes. It is not improbable that *Gigartina corymbifera* may eventually find an appropriate place in America's carrageenin industry.

FIG. 11. *Iridophycus flaccidum*, source of the phycocolloid, iridophycin, a newly introduced colloid in stabilizing chocolate milk. (*Courtesy of the New York Botanical Garden.*)

Other Red Seaweeds. The red seaweeds now used in America besides *Gelidium*, *Gracilaria*, *Chondrus* and *Gigartina* are *Iridophycus*, *Porphyra* and *Rhodymenia*.

Iridophycus. Two species of this genus are utilized, namely, *I. flaccidum* and *I. splendens.* They yield a colloid, iridophycin, which has properties similar to those of carrageenin. Both species have lanceolate or ovate-lanceolate blades with short stipes, arising from disk-shaped holdfasts. The thalli are soft in texture when fresh, turning tough and rubbery when dry. *I. flaccidum* reaches two feet in length and is greenish-olive when growing in the mid-littoral, deep purple in the lower littoral. *I. splendens* reaches four feet in length, generally grows in deeper waters than the former species and is of a rich purple in color. Both grow on rocks somewhat sheltered from the surf. Commercial iridophycus comes from near Crescent City, Pt. Arena, and Jenner in California, and south of Coos Bay in Oregon. Harvesting season extends from June to December. The plants are picked by hand from the rocks at low tide, and during one low tide, lasting

from two to three hours, one man can pick from 200 to 300 pounds of the fresh seaweed in favorable locations. A good picker is known to have gathered as much as 400 pounds in one tide. Much depends on the location, the tide, and especially on conditions of the sea as a result of the velocity and direction of the wind. There are many beaches with excellent growths of *Iridophycus*, but unfortunately they are inaccessible by penses involved in drying, in addition to harvesting cost. There is only one firm engaged in processing iridophycin. It buys the fresh seaweed and takes care of the drying itself.

Porphyra. While most species of *Porphyra* may be utilized as food, the species commonly harvested is the perforated laver, *Porphyra perforata* J. Ag., of California. This forms large, brownish-purple, deeply lacinate, lanceolate to

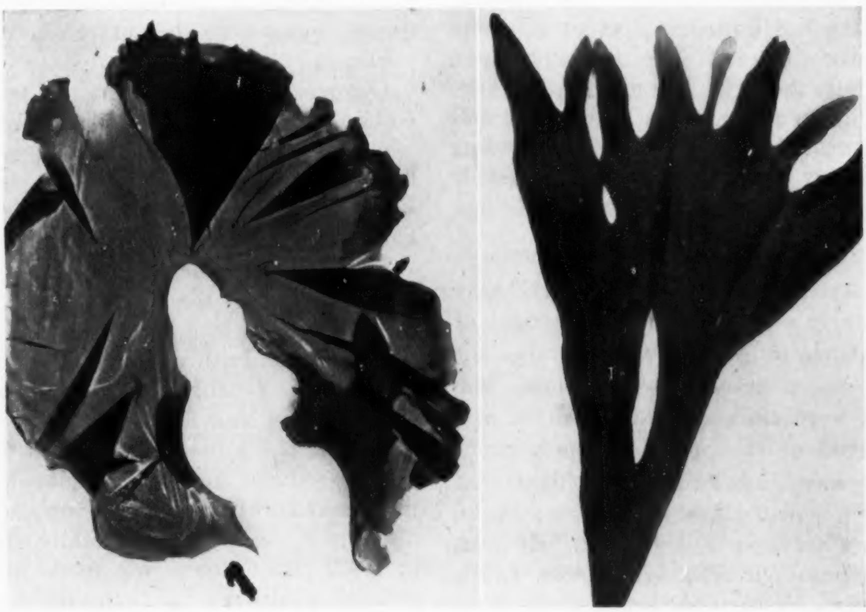

FIG. 12. Two American food seaweeds, California or purple laver (*Porphyra perforata*, left) and East Coast dulse (*Rhodymenia palmata*, right). Indians of the Pacific Coast relish the laver, and the Chinese use it in their seaweed soup. In eastern metropolitan markets dulse is occasionally on sale, to be eaten raw as a relish. (*Courtesy of the Journal of The New York Botanical Garden.*)

land. Commercial gathering started in the summer of 1944. In 1944 and 1945 about 14 tons of the fresh seaweed were harvested from California and about 16 tons from Oregon. The 1946 production was expected to be over 30 tons. *Iridophycus* dries to about 22% of its weight when freshly harvested. It costs about five cents per pound to gather the fresh weed, or about \$100 per ton. A ton of the sun-dried iridophycus will therefore be worth around \$700, considering ex-

irregularly shaped membranes with deeply ruffled margins. The blades may reach five feet in length, but generally are about two to three feet long. The laver grows on rocks in rather sheltered places from the mid-littoral to the limit of high water. Bonnot reported that 300,000 pounds of dried laver were harvested in 1929 by white men and Indians in northern California and by Chinese in central and southern California. The Chinese harvesters usually come to the

laver grounds in the fall and burn, with driftwood, the rocks on which they expect their laver crop to grow. By early spring these rocks are densely covered with the *Porphyra*. In harvesting, the laver is merely pulled from the rock by hand and is dried in the sun in the form of rectangular sheets. At present, California laver is worth \$600–800 per ton.

Rhodymenia. American dulse is *Rhodymenia palmata* (L.) Grev., found along the Atlantic shores from North Carolina northward. Most of it comes from the Canadian Maritime Provinces, especially from the Bay of Fundy, where it grows on rocks in the low littoral and is harvested by hand picking during spring low tides. No data are available as to its production.

Utilization of Seaweed Products

In America, as elsewhere, there have been three stages in the development of the utilization of seaweeds and their products. During the first stage, seaweeds were merely gathered, dried and employed as food or medicine without other processing. In America this started about a century ago with Irish moss as the first seaweed thus utilized. At present we have, besides Irish moss, edible kelp from *Nereocystis*, laver of the West Coast and dulse of the East Coast. Perhaps we should also include kelp meal which is made into stock feeds or tablets for humans. In the second stage of development seaweeds were utilized to supply non-colloid chemicals and had to be processed to yield these products. This started just before World War I, flourished during the war, and came to an end a few years after the war. It was short-lived, but it had reached, within a few years, a stage of glory not matched by even the seaweed industry today. During this period, high grade potassium chloride, acetone, calcium acetate, iodine and decolorizing carbon were produced in large quantities from the California giant gelp, *Macrocystis pyrifera*. At present these materials may be obtained more cheaply from other sources, and seaweeds are no longer used in America as raw materials for non-colloid chemicals. In the third and most recent stage, interest in seaweed utilization has shifted to the seaweed colloids, or phycocolloids. They are extremely valuable as gelling, suspending, emulsifying, thickening and body-producing agents, and have found extensive uses in food, drugs, cosmetics and other industrial products.

Commercial production of seaweed colloids started during World War I, when algin was made at San Diego as a by-product in the kelp industry. Algin, however, did not become the principal kelp product until the late 1920's and early 1930's. Agar, another important colloid, was first made in Tropico (now Glendale), California, in 1920. Although the colloid of Irish moss has been in use for over a century in making blancmange in the New England states, it was not until the late 1930's that it began to be produced in the present purified powdered form. Large commercial production of carrageenin actually started in 1942. Iridophycin was made in commercial quantities in 1945; its production at present is still small in comparison with that of the other phycocolloids. Uses of seaweed products in America have been discussed also elsewhere.[1]

1. Commercial Intelligence Jour. **67**: 129, 409. 1942.
Smithsonian Inst. Rep. **1941**: 401. 1942.
Fish. Market News **5**(6): 1. 1943.
Bull. U. S. Bur. Fish. **24**: 167. 1905.
Jour. Soc. Arts. **10**: 185. 1862.
Sci. Monthly **58**: 24. 1944.
Sci. Monthly **59**: 37. 1944.
Food Industry **17**: 10, 11, 122, 140, 141, 230, 232, 234, 258, 259, 356, 358. 1945.
Chem. & Met. Eng. **52**(6): 97. 1945.
Jour. New York Bot. Garden **47**: 1, 32. 1946.
Phycocolloids: useful seaweed polysaccharides. *In* Jerome Alexander, Colloid chemistry, theoretical and applied. Vol 6. 1946.

Non-Colloids. There are two general groups of non-colloid seaweed products, cured seaweeds and ground seaweeds. Cured seaweeds are sun-dried, sometimes partially bleached, and are used in the form of whole plants. They chiefly serve for food or in making food preparations, and include bladder kelp, laver, dulse and Irish moss. The bladder kelp was used in the last war as a kombu (Japanese kelp) substitute by the Japanese in the United States, and the Chinese use laver extensively in their so-called seaweed soup. Dulse is eaten raw and dry as a kind of salad or relish, or is employed as a thickener in soups, sauces and gravies. Use of Irish moss in the preparation of the well-known blanc mange has been centuries old on the East Coast, and for its preparation the following directions have been given:

"Soak half a cup of dry moss in cold water for five minutes, tie in a cheesecloth bag, place in a double boiler with a quart of milk and cook for half an hour; add half a teaspoonful of salt or less, according to taste; strain, flavor with a teaspoonful of lemon or vanilla extract if desired, and pour into a mold or small cups, which have been wet with cold water; after hardening, eat with sugar and cream."

Stock feed. Ground seaweed is made entirely of kelps, from both macrocystis and nereocystis, hence generally called kelp meal. Its principal use is as stock feed, and analyses of it show the presence of large amounts of various minerals as well as vitamins A, B, F and G. One company produces a meal consisting entirely of dried and ground macrocystis, while another concern uses the same plant but mixes it with fish meal and fish press-water concentrate, fortified with various beneficial substances. There are four kinds on the market under the trade name "Manamer", one for hogs and pigs, one for chickens, one for horses and one for cattle. These are all supplementary feeds to be mixed with grains and other established rations.

The value of seaweeds as stock feeds has been quite well established. Along the coast, the seaweeds may also be used *in toto.* They should, however, be rinsed in fresh water to leach out the excessive salts which, if taken in large quantities, may have an adverse effect on the health of the animals. It has also been found in Europe that animals may require from a few days to a week or more to readjust their food habits from an ordinary ration to a predominantly seaweed diet. The value of seaweeds as stock feed differs with the kind of plant used, with the season of harvesting, with the different animals feeding on them, and with the individual preferences of the animals for the kind offered as food.

Medicinal tablets. Kelp meal from macrocystis is also made into tablets for human consumption to supply mineral salts needed by the human system. There are at least three concerns engaged in this trade. One company at Anacortes, Washington, makes the meal from the bladder kelp in the Puget Sound region, and sends it to New York for processing into kelp tablets. At Vancouver, British Columbia, a new kelp company was recently formed to utilize local kelp resources for similar and other purposes. Kelp meal is also used as a constituent in the diet of hatchery-reared fingerlings at Seattle, Washington, being employed on a basis of 2% of the weight of the ration fed.

Manure. Utilization of seaweeds as manure in America, as elsewhere, has been centuries old. In Rhode Island, for instance, as late as the 1890's, seaweeds formed an important source of farm

Textile Age. 1946.
Nat. Mag. **36**(3): 127. 1943.
Cal. Fish and Game **28**(4): 199. 1942.
Marine products of commerce. 762 pp. 1923.

manure, and in recent years, kelps have been used in various coastal regions as fertilizer. Farmers living at Encinitas, California, gather the drifted kelps on the beach to fertilize their avocado orchards. One chief obstacle in using whole seaweeds as manure is the bulkiness of such materials which contain more than 95% of water. Since the drying and grinding processes do not decrease the value of kelps as fertilizer, use of kelp meal eliminates this trouble. It is expected that kelp meal may eventually be marketed as regular manure for special types of crops.

Colloids. As already mentioned, there are produced in America, at present, four kinds of phycocolloids, namely, algin, agar, carageenin and iridophycin. Of these, algin comes from the brown seaweeds, the other two from red seaweeds.

Algin. The term "algin" generally refers to the sodium salt of alginic acid, a polyuronic acid composed entirely of *d*-mannuronic anhydride residues. Like the other seaweed colloids of commerce, algin is useful wherever a hydrophilic colloid possessing marked gelling, suspending, emulsifying, thickening and water-holding properties is required. Unlike the other phycocolloids, it is chemically active, reacting readily with various metallic salts and acids. Consequently, in certain respects, its uses are limited, while in others it serves especially well by virtue of its reactivity. For example, many of the present industrial uses of algin are based on the fact that addition of a calcium salt to an algin solution produces an immediate precipitate of gelatinous calcium alginate. Thus, by the controlled release of calcium ions, through the use of a relatively insoluble calcium salt, such as calcium citrate, the solutions may be either thickened or converted into rigid gels, in accordance with the amount of the calcium salt added. The rate of the setting of the gel may also be controlled by the introduction of salts, such as a soluble phosphate, which form calcium salts more insoluble in water than calcium alginate.

In the preparation of algin solutions for use in food and other industries, water should be warmed to about 140° F. and the solution should be vigorously stirred. Algin solutions are susceptible to bacterial growth. Therefore, preservatives are commonly added to them if they are to stand for prolonged periods.

The most important use of algin is undoubtedly in stabilizing ice creams, where a colloid is needed to impart smooth body and texture and to prevent formation of large ice crystals during storage. It is prerequisite that such a stabilizer will not in any way mask the flavor of the resulting product. Ice cream mixes made with efficient stabilizers whip fast and produce sufficient overrun. Such ice creams show a smooth clean meltdown without any serum drainage or wheying off. Previously, gelatin was the sole standard ice cream stabilizer, but since algin was introduced about ten years ago, it has been rated by most experts as a better material than gelatin. At least 50% of the factory-made ice creams in the United States are now stabilized with algin.

Some years ago algin was used extensively as a chocolate milk stabilizer. In recent years, however, carrageenin has become the most important agent for this purpose, and while some algin is still being used, it is always employed together with some carrageenin. Until very recently, orange and lemon ices have been stabilized almost exclusively with gums, but algin is now successfully used for the same purpose. It also fills the role more satisfactorily in stabilizing sherbets, where the more costly agar, which required a higher temperature to dissolve, was previously used. To reduce serum drainage, algin is put

into cream cheese and cheese spreads and also whipping creams for decorating fancy cakes. It also serves as a gelling agent in milk puddings by virtue of its reaction with calcium in the milk. Algin is also employed in many different ways in food preparations, such as jellies, jams, icing, meringues, fillings, milk powders, oleomargarines, candies, fruit juice powder and sausage casings.

Algin is useful also in pharmaceutical preparations, emulsifying the petrolatum base, for instance, in making sulfanilamide ointments for surface wounds. It serves as a constituent in pills and tablets, and is also used occasionally in emulsions to carry medicinals such as vitamins. In the cosmetic industry algin is now considered to be one of the most useful colloids, its value residing in its ability to produce standard preparations of controllable consistency, which are transparent, water-white and almost odorless. Ordinary preparations made with karaya gums, for instance, have a grayish-brown color, and those made with tragacanth are quite opaque. Another advantage of algin preparations is the wide range of controllable viscosity, effected by the addition of calcium ions to sodium alginate solutions. The preparations may either be thickened to creams or converted into jellies, depending on the amount of the calcium salt added. It is an excellent vehicle for hand lotions of the saponified type, and a valuable base for tooth pastes and for greaseless, water-soluble ointments and lubricating jellies, replacing tragacanth and other gums, because it is compatible with most of the ingredients in the official formulas.

Sodium and ammonium alginates are both used extensively in the preparation of vehicles for resin emulsion paints, the algin serving as an emulsifier. Algin dissolves shellac to form a lacquer which dries to a tough, tenacious film. Treatment with dilute acids or calcium chloride solution renders this film insoluble, hence useful as a water-proof varnish. Coated over asphalt paints for steel plates and insulated wires, algin helps to prevent the painted surfaces from adhering to each other. During the last war, algin was used as a stabilizer for camouflage paints. Copper alginate serves as a dressing for canvas and burlaps to prevent mildew. Algin is used in the preparation of a new type of fire-retarding compound, recently developed at the United States Forest Products Laboratory. This consists of finely ground fire-retarding chemicals dissolved and suspended in an aqueous sodium or ammonium alginate solution. Best results are obtained with monoammonium phosphate as the fire-retardant, although a mixture of borax and boric acid also gives satisfactory results.

In dentistry algin serves as a dental impression material. Algin-based preparations do not produce as accurate molds as do the traditional agar-based ones. They are, however, more convenient to use and are therefore extensively employed by dentists for general work. Recently ammonium alginate has been adopted for coating dentures made of acrylic resin to take the place of tinfoil which has not been available for this purpose because of the war. Two coatings of the alginate solution are applied with a brush to the gypsum molds when these are still warm from the wax removal. When dry they are immersed in calcium chloride solution, thus converted *in situ* into insoluble calcium alginate coatings. Use of algin in coating dentures is easy and gives very uniform results, and is expected to continue even when tinfoil comes back in sufficient quantities.

In the rubber industry algin serves as a latex-creaming agent; for this purpose ammonium alginate is used instead of the sodium salt. Algin is also useful in treating boiler water for preventing in-

crustation. It reacts with the calcium salts, forming globular flocculent precipitates; these envelop other sediments to give a soft pasty sludge which can be readily blown out of the boiler at regular intervals. As a sizing material algin has the advantage over starch in that it fills the cloth more completely, is tougher and more elastic. In printing pastes algin is widely used as a thickener. Triethanolamine alginate, an algin derivative, is employed as a coating material for solid surfaces. Incorporated in insecticide sprays, algin activates and greatly reduces the necessary effective chemical. Algin is also employed in the purification of beet juices in sugar manufacture, in oil-well drilling muds to seal off porous formations, as a medium for separating plates in the manufacture of storage batteries, as a binder for printer's ink, in the finishing of leathers, and in the preparation of a color-absorbing material.

Agar. Chemically the sulfuric ester of a linear galactan, agar consists of a long chain of *d*-galactopyranose residues, terminated at the reducing end by one residue of *l*-galactopyranose. It is a valuable colloid principally because of its strongly hydrophilic nature and its high gel-strength quality. It is used where bulk is wanted, or where a suspending, stabilizing, thickening or gelling agent is desired. An important use of agar is as roughage. Being not digestible in human systems, agar, when taken in the form of powder or flake, serves as a bulk-producer. This problem of bulk supply is one that only civilized man, accustomed to highly refined food, has to encounter, and agar flakes successfully take the place of the coarse materials that his ancestors ate normally with every meal. For similar reasons agar is incorporated in certain types of breakfast feeds and special bakery products for victims of constipation.

Because of its moisture-holding ability, agar is extensively used in making fruit cakes. These are generally prepared weeks before they reach the customers, and the addition of agar helps to keep them in good condition for a long period. Agar is used in stabilizing icings, in making chiffon pies, in meringues and fillings. It is employed in making confectionaries, chiefly in jelly candies and marshmallows, and in preparing malted milks and acidophilous milks. It also serves as a thickening and gelling agent in the canning of pickled tongues, poultry and the softer types of meat and fish.

Agar is a constituent of petroleum-agar emulsions. In such preparations, however, it does not serve as a laxative, as the public is led to believe, since it is present in too small a concentration, generally less than 1.5%, to be effective. It serves primarily as an emulsifier and helps to make the preparation easier to take. Agar is employed as a vehicle for lactic acid to combat toxicogenic bacteria in the intestines. An interesting use in medicinal preparations is in the so-called "seal-ins" for pills, a type of coating which regulates the rate of solution of the capsule and consequently the timing of its opening. The agar is added in tiny particles and distributed in the waxy material of the coating. By virtue of its water absorption, agar assists in the release of the coated medicinal preparation in the desired place. Agar is also used in the coatings of certain gentian violet capsules employed in the treatment of infection with *Oxyuris vermicularis*. It is also a constituent in a preparation for the treatment of Coccidioides infection in chickens.

Agar is best known, however, as the standard material in the preparation of solid microbiological culture media, and as such, is an indispensable material in the routine sanitary analyses of water and milk. Its importance in public health work and medical and scientific

research is so significant that during World War II the United States Government had to freeze the available agar supply so that the nation's health would not be impaired by lack of this seaweed colloid. In scientific laboratories agar serves as an embedding medium for microtome sectioning, as a vehicle in the standard *Avena* test for plant growth hormones, and as a coagulant for barium sulfate precipitation. In agriculture agar is useful as an insecticide activator and carrier, and in making coatings for nitrogen bacteria cultures.

Agar is extensively used in prosthetic works. It is the basic material in most dental impression materials. In highly critical works, such as inlays and fixed bridges, agar-based compounds are practically the only materials used. Though agar alone is unsuitable for use in certain photographic materials because of its tendency to stick to gelatin and its insolubility in organic solvents or in alkaline solutions, the esters of agar are soluble in a number of organic solvents and can therefore be employed as coatings or backings for photographic films, from which they may be later removed by means of alkaline solutions. Backings are required to keep the films flat and, to some extent, to carry colored materials for minimizing halation.

In the hot-drawing of tungsten wires for electric lamps a lubricant is necessary. At present the lubricant is an agar gel in which powdered graphite is mechanically held in suspension. Formerly the industry used an expensive material known in the trade as "aqudag", procurable only from limited sources. The agar-based lubricant is not only relatively inexpensive and easily procurable, but also more efficacious. The agar gel is able to hold in suspension larger particles which, within certain ranges of size, provide more complete and uniform protective covering on the exterior of the wire.

Shredded agar has been recommended to be incorporated in small amounts in tobacco to retard excessive evaporation of moisture. In hectograph duplicators, agar is used to make the gelatinous rolls. It is also used in the manufacture of submarine storage batteries.

Carrageenin. Like agar, carrageenin is the sulfuric ester of a galactan. It has additionally, however, a certain percentage of 2-ketogluconic acid. The most important use of carrageenin in America is undoubtedly that of stabilizing chocolate milk. Previous to the introduction of a stabilizer, the chocolate-flavored milk on the market always had a sediment of cocoa particles at the bottom of the bottle. The bottle, therefore, had to be shaken vigorously before the drink was poured. The sediment usually adhered so firmly to the containers that great difficulty was encountered in washing them. Now, with the addition of a small amount of carrageenin, these difficulties are largely eliminated. To make chocolate milk, a chocolate syrup is first prepared. The syrup is made by adding a mixture of cocoa, salt and carrageenin to invert sugar solution at about 190° F., and contains about 0.4% carrageenin. One gallon of this chocolate-flavored syrup is then mixed with 11 gallons of milk, and the mixture pasteurized and finally bottled. The finished product thus contains only 0.04% of the Irish moss extract; yet the cocoa fibers are effectively held in a homogeneous suspension and the butter fat does not rise to the top.

Carrageenin is used in food preparations in similar ways as agar and algin. It is employed extensively in making puddings, cheese spreads, pie fillings, cake frostings, jelly fillings, jams, preserves and candy. In the dairy industry, besides being the principal stabilizer in making chocolate milk, it is also employed in stabilizing ice cream, ices and sherbets, and its use in this respect is

said to be increasing fast. It is used in emulsifying cod-liver oil as well as mineral oil. "Decoction Chondri" prepared from carrageenin is probably the best known phycocolloid pharmaceutical emulsifier. The National Formulary recommends a 3% Irish moss solution for the "Mucilago Chondri," which is used by itself as a demulcent and frequently as a vehicle for other medicaments. When employed as the base of cough medicines, carrageenin is said to give them body and to produce a slight soothing effect. It is reported that in Irish bar-rooms in New York, carrageen is soaked in whisky and the resulting liquor offered to patrons as a cough remedy. Carrageenin is also used as a granulating agent in such preparations as aspirin tablets.

In the cosmetic industry, carrageenin is extensively used as a binder, emulsifier, gel-former and bodying agent. It is a regular ingredient in many tooth pastes, and a thick mucilage is used in deodorant pastes. It serves as the base of sulfonated oil-curling jellies, and is also an ingredient of compact powders and rouges. It is employed in making glycerine jellies for chapped hands, and as vehicles for the saponified type of hand lotions.

During the last war, because of a shortage of agar, one concern made a special carrageenin preparation under the trade name "Carragar" to serve as an agar substitute in the preparation of solid microbiological culture media. This contains additional potassium salts which help the carrageenin to form a firmer gel, approaching agar gel. Normally, carrageenin by itself forms a weak gel, even at high concentrations. The product apparently is quite successful for certain media, but for the standard techniques, the excessive syneresis of Carragar media eventually interferes with the counting of colonies on plates.

Before liquor prohibition in the United States, one of the most important uses of carrageenin was in the fining of beers and ales. In the early stages of beer brewing, the cloudy solution of malt extracts contains insoluble materials and undesirable proteins. These can be removed by natural slow setting or rapid fining with the help of a clarifying agent. Carrageenin has the ability to combine with the tannin of hops to form a gelatinous mass which absorbs the suspended impurities. The resulting flocculent mass is easily removed as a scum. Carrageenin is still being used in the liquor industry as a clarifying agent, although it has been partially replaced by other chemical finings.

Carrageenin imparts to certain types of leather a desirable gloss and stiffness. It is principally used in the finishing of straight grains and grain upper leathers. A solution is brushed on the leather, which is then glazed by rubbing with glass cylinders. This mucilaginous substance smooths and holds down the tiny rough projections on the surface of unfinished leather. In inner soles, carrageenin is used as a filler to impart stiffness and body to them. Its use also helps in the water-proofing of very heavy leather. When used in shoe polish and leather dressing, carrageenin serves to restore the finish to worn, scuffed leather, and one shoe manufacturer in New England alone used to import annually about 12,000 pounds of Irish moss from Ireland solely for leather finishing.

Like algin, carrageenin is extensively employed in making water paints. Casein paints stabilized with it are easily applied and adhere well to the surface while drying. Carrageenin was among the first hydrophilic colloids used in the creaming of rubber latex, although at present ammonium alginate is the only creaming agent from seaweed sources.

Iridophycin. Like agar and carrageenin, iridophycin is a galactan ethereal sulfate, although of a much simpler con-

stitution. Its introduction to industry is very recent, and its use is still limited to stabilizing chocolate fibers in the preparation of chocolate milk. It is said to be better than carrageenin when cold mix is used in making the preparation.

Laminarin and Fucoidin. There are at least these two other seaweed colloids which could be produced in commercial quantities in America. However, there is as yet no commercial applications for them, and hence attempts at commercial production of these substances have not been made by the industry.

Summary of Resources

Production of acetone, iodine, kelp-char and potash from kelp on the Pacific Coast of the United States as a result of World War I has been superseded since the late 1930's by industries on both the Atlantic and Pacific Coasts that produce other products from seaweeds, namely, agar, algin, carrageenin and iridophycin.

The extensive industrial uses of these products can not be summarized beyond what has been done in the foregoing account without omitting some of the uses.

According to investigations made in the years 1911 to 1913, there were at that time about 390 square miles of kelp beds with about 60,000,000 tons of kelp growing along the Pacific Coast from Cedros Island, Mexico, to western Alaska. This estimate has since been regarded as too high.

These Pacific beds consist mainly of *Macrocystis pyrifera, Nereocystis Luetkeana* and *Alaria fistulosa*. The greatest recorded production from them in California was 394,974 tons of fresh kelp in 1917; the production of 1918 may have exceeded that amount. In 1945 a little over 59,000 tons were harvested.

The economically important kelps on the Atlantic Coast are *Laminaria saccharina* and *L. digitata.* Data are not available regarding the supply and harvest of them, but since about 300,000 pounds of algin were produced from them in 1944, and since algin constitutes about 4% of these kelps, the production that year was at least 4,000 tons, or less than 10% of the current Pacific Coast production.

The two principal sources of agar are *Gelidium cartilagineum* of the Pacific and *Gracilaria confervoides* of the Atlantic Coast. In 1944, 240 tons wet weight, 80 tons dry weight, of agarweed were recorded as having been harvested along the California Coast.

Carrageenin is obtained from *Chondrus crispus* (Irish Moss) and *Gigartina stellata.* The former abounds in commercial quantities along the Atlantic Coasts of both Europe and America; the latter only along the coast of Europe. Harvesting in America is centered around Scituate, Mass., and the production in 1946 was expected to reach half a million pounds dry weight.

Iridophycus flaccidum and *I. splendens,* both of the Pacific Coast, are the sources of iridophycin, a colloid with properties similar to those of carrageenin.

Cell Walls and Synthetic Fibers

Many theoretical chemists now discount much chemical and botanical work in cell wall research before 1920 and all current work which indicates the presence and importance of non-cellulosic materials in determining cell-wall properties.

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History and Terminology

THE pioneer microscopist, Robert Hooke (40), anticipated the discovery of a process of synthetic fiber manufacture by more than two centuries with the statement:

"—And I have often thought, that probably there might be a way found out, to make an artificial glutinous composition, much resembling, if not full as good, nay better, than that Excrement, or whatever other substance it be out of which the silkworm wire-draws his clew. If such a composition were found, it were certainly an easie matter to find very quick ways of drawing it out into small wires for use. I need not mention the use of such an Invention, nor the benefit that is likely to accrue to the finder, they being sufficiently obvious. This hint, therefore, may I hope, give some Ingenious inquisitive Person an occasion of making some trials, which, if successful, I have my aim, and I suppose he will have no occasion to be displeased".

In 1885 Count Hilaire de Chardonnet (15) obtained a British patent covering the first successful commercial process for the preparation of "artificial silk." Plant fibers, after treatment with strong nitric acid, were dissolved under pressure in a mixture of alcohol and ether. The fine filaments of the extruded solution were coagulated in water and subsequently denitrated by treatment with dilute nitric acid, chloride of iron and ammonium phosphate. The final product was a glossy, flexible fiber possessing many of the properties of silk.

The usefulness of plant fibers in the preparation of "glutinous compositions", from which textile filaments could be spun, was shown concurrently in processes other than that described by Chardonnet. In 1851 and 1857 it was observed (54, 65), apparently independently, that in ammoniacal solutions of cupric oxide, plant fibers first gelatinize and then disappear into a viscous fluid. In 1897 Fremery and Urban, under the name of Pauly (55), patented the first cuprammonium process for fiber manufacture.

In 1892 other investigators (20, 21) discovered that when cotton fibers are treated with sodium hydroxide of mercerizing strength to form "soda cellulose" and this soda cellulose is then treated with carbon disulfide, a so-called "cellulose xanthate" is formed. A solution of this xanthate in dilute sodium hydroxide has very high viscosities—hence the name "viscose". From the solution the dissolved material may be recovered in the form of textile fibers or molded plastics. Its low cost and versatility has assured its industrial importance.

Schutzenberger (64) treated cotton fibers with hot acetic acid anhydride and reported in 1870 the formation of "cellulose acetate". In his reaction mixtures he recognized the formation of the triacetate. Franchmont (29) in 1879 used concentrated sulfuric acid or zinc chloride to catalyze the reaction. The process patented in 1906 (49) was an impor-

tant step toward the present industrial usage of acetone-soluble derivatives. As described recently (67):

"Briefly the process consists in swelling the cellulose fiber so that all the hydroxyl groups are available for acetylation. Acetylation is carried out, using acetic acid anhydride and acetic acid with sulfuric acid or some other suitable catalyst. The cellulose is acetylated to the triacetate and an excess of acetic acid is used as a solvent.

"The cellulose acetate thus formed is then deacetylated to the proper acetyl content. It is then precipitated from the acetic acid solution, stabilized (if necessary), washed free from acids and dried.

" . . . In the utilization of cellulose acetate for industrial fibers, in particular, it is necessary to reduce the acetyl value so that the acetate becomes soluble in acetone".

The selection of a "trade name" for these fibers has been described as follows (70):

"For almost the whole of that fifty year period, the several man-made fibers which survived the experimental stage and emerged into a commercial world were called 'artificial silks', a frank declaration of the motive which produced them and of the light in which they were viewed by the textile craftsman and the consumer. About twenty years ago the producers and merchants of these new members of the textile family invented the generic term 'rayon' to replace the term 'artificial silk'. . . . It was a moment of historic textile importance because it first emphasized that these man-made fibers, despite any outward similarity to silk, and despite the natural tendency to use them in imitation of silk, were actually new and destined to stand or fall on their own distinctive properties and values".

Names now used most commonly for man-made textiles, in which plant tissues form the basic raw material, are "artificial silk", "rayon" and "synthetic fabric". Although the suggestion has been made that the term "synthetic" be reserved for fibers such as nylon alone, no decision has been made concerning a general terminology which will be acceptable to those concerned. The term "synthetic" now serves to distinguish, in general, all man-made fibers from native fibers such as cotton, silk and wool. In the present article it applies specifically to the "man-made" textile filaments manufactured from plant cell walls.

Plant Fibers and Synthetic Textiles

It is worthy of particular consideration from both the biological and the industrial standpoints that, from all of the available plant tissues, fibers were chosen as the raw material for rayon manufacture. Seed fibers such as cotton, bast fibers such as flax, and wood fibers such as are obtained from spruce and pine, are all characterized by the formation of unusually thick cell walls. These walls play such an important rôle in determining the physical and chemical properties of the natural fibers that the problems connected with processing for synthetic fiber production have dealt primarily with cell-wall reactions to the reagents, temperatures, and pressures employed.

The substances which are commonly described in cell walls, in general, may be listed briefly as follows:

1. Cellulose { crystalline, amorphous }
2. Hemicelluloses { Pentosans, Galactosans, Mannosans }
3. Pectic Substances { Protopectin, Pectin, Pectates }
4. Lignin
5. Suberin and Cutin
6. Protein, resins, gums, coloring matter, tannin, callose and minerals.

In the cotton fiber, materials from groups 1, 3, 5 and 6 are found. In bast and wood fibers of various types, materials from all groups may occur. In no cell walls are the different constituents likely to be present in complete segregation, and the colloidal mixtures in which they naturally occur render their separation and identification difficult.

Plasticity and Deformability in Native Cell Walls

In the course of the manufacture of synthetic textile filaments, natural plant

fibers lose their identity, and their walls, once tough and resilient, are transformed temporarily into a soft continuous deformable mass. From the view point of industrial processing, this phenomenon may seem to be unique in cellular experience, and the erroneous conclusion may be drawn that living cells are not confronted with the need for such properties as plasticity and deformability.

Cells Without Walls. For more than a century it has been an accepted fact that the protoplast and not the cell wall is the essential part of a cell; that in the phenomenon of growth, the protoplast precedes the cell wall; and that, in fact, the colloidal protoplasm is the stuff from which cell walls are made.

In some cases, for the purpose of maintaining their plasticity and deformability during important periods of their life history, protoplasts dispense with their cell walls. Close examination of fallen tree trunks in a moist woodland often reveals strands of slime mould flowing slowly from the under side to the exposed surface of the log, the protoplasts unencumbered by cell walls. Other types of protoplasts first build heavy cell walls and later emerge from the enclosure to continue their existence in a new locality. Observations of cells such as these serve to emphasize the fact that when there is a demand for the maximum in plasticity and deformability, the cell either has no wall at all or uses a wall only as a place of temporary abode.

Cell Walls and Cell Enlargement. In the process of growth, cells increase in number by division. After cell division has taken place the protoplasts of the daughter cells often enlarge to many times their original volume, and their cell membranes are extended to accommodate the increased surface area.

During this period of division and enlargement, they are known as "meristematic cells", and the region of the plant in which they are located is known as the "meristem". Their cell walls are characterized by plasticity and extensibility, and chemical analyses show that these physical states are associated with certain membrane-building materials. In this connection two authorities observe (84):

> "Macrochemical experiments prove the existence of cellulose in the walls of the meristem, but its presence is masked by association with other substances.
>
> "Protein, closely linked to the cellulose, is found by macrochemical experiments to be most probably the substance which prevents the reaction with iodine and sulphuric acid.
>
> "Pectin is present in each case, though not directly linked to the cellulose in the meristem wall of radicle and root.
>
> "The middle lamella in the meristem is never of calcium pectate but is probably a mixture of pectin and protein".

Microscopic and microchemical analyses of meristematic tissues indicate more specifically the relation of the chemical constitution of young cell walls to their observed physical properties. In general, the primary wall is composed of non-cellulosic materials (26), and this portion of the wall, not the cellulose-rich secondary lamellae, plays the active rôle in cell enlargement.

Epidermal cells of the oat coleoptile represent a type in which cellulose is deposited before cell enlargement is completed (28). The enlargement takes place in the original plastic membrane, however, and in the course of wall-elongation the cellulose is separated into hoop-like bands. The doubly refractive cellulose and the non-double-refractive, plastic materials of both the unelongated and the elongated membranes, can be distinguished in polarized light. During a later period of growth these elongated walls are again made more rigid through the deposition of lamellae rich in cellulose between and within these separated doubly refractive bands. Cells of different types thus control their growth economy through the ingenious use of non-cellulosic and cellulosic materials.

Cell Walls of Root Hairs and Cotton Fibers. Root hairs serve as unique examples of the importance of non-cellulosic materials in enlarging cell walls. Each hair is formed through the elongation of a single epidermal cell of the root; its function is the absorption of water and nutrient materials from the soil. This absorption is facilitated by an intimate physical contact between the root hair wall and the soil particles. Plasticity is again at a premium, and, in addition, the cell wall must permit the passage of aqueous solutions without being either dispersed or dissolved by them.

Stier (78) has found that stretching of the wall takes place more readily at the tip of the root hair than along the sides, and that when bursting occurs, the rupture is almost invariably at the tip. Cormack (19) has shown that these localized variations in hydrophilic properties are brought about by a decreasing degree of calcification of the pectic material from the base to the tip of the hair. It follows that the physical properties of root-hair walls are in large measure controlled by the chemical and physical state of the pectic material which they contain. In most root-hair walls cellulose is not found (41); when present it is reported to be in the form of a very thin layer upon the inner surface of the primary wall of calcium pectate (60).

This type of wall composition is shared with primary walls of young cells, in general. These are composed largely of pectic material and protein (26), and cellulose deposition takes place toward the end of the period of cell enlargement, when loss of plasticity is no handicap. Root hairs represent a special group of cells in which wall plasticity is of continued importance, and cellulose formation and deposition rarely take place.

The function of cellulosic and noncellulosic materials in determining the physical properties of native cell walls is brought out even more clearly by a direct comparison of the cotton fiber and the root hair. Both the hair and the fiber arise through the elongation of single cells upon the surfaces of the root and seed, respectively. The primary walls of both are rich in calcium pectate and contain little or no cellulose. In the course of the apical growth, the tips of both hair and fiber are less highly calcified than the lateral walls.

In later stages of development the marked differences between root hairs and cotton fibers appear. The protoplasm of the cotton fiber produces large quantities of cellulose and uses it in the formation of many secondary lamellae; the protoplasm of the root hair produces little cellulose, and in many types it is entirely lacking. The cell wall of the fiber is thick and firm and is not easily deformed; the cell wall of the hair remains more or less plastic and deformable throughout its entire period of existence. In the mature state the cell wall of the fiber contains a very high percentage of cellulose and a low percentage of pectic material, protein and wax (32); the mature root hair resembles, in structure and composition, the primary wall of the fiber.

Examples may be drawn from various parts of the plant kingdom to illustrate the fact that the properties of extreme plasticity and deformability are achieved in the native cell walls by the use of noncellulosic materials; that membranes rich in cellulose are no longer plastic; and that extraordinary procedures are involved in reversing this state of rigidity in a mature cell wall. Industry relies upon more or less drastic chemical and physical processes. The cells themselves usually bring about such reversal through the use of enzymes (17, 12).

These observed properties of fiber cell walls and comparisons with the properties of walls of other plant cells have served as a basis for some phases of the

research dealing with the colloidal behavior of cotton fibers and wood fibers during the manufacture of synthetic textiles. In the experiments attempts have been made to follow the various types of cell wall components through their progressive stages of reaction to reagents used in xanthation, nitration and other types of industrial procedures. The results, in turn, have been used in efforts to correlate the more fundamental aspects of cell wall composition and structure with the properties of fibers in both the processed and unprocessed states.

Molecular and Colloidal Interpretations of Structure and Physical Properties

Variations in experimental results and different interpretations of chemical, physical and microscopic data have left many of the important considerations undecided. The accumulated information has led, in general, to the development of two different viewpoints of the structure of the native cell wall and the relation of wall materials to synthetic products. One interpretation holds that the cellulose molecule is the functional unit which determines the properties of native cell walls as well as their synthetic derivatives. The other, following classical colloidal lines, explains the same properties upon the basis of a heterogeneous chemical system, established through the vital activity of the colloidal protoplasm and persisting in its more general characteristics throughout the "purification" treatments involved in industrial processing. For the purpose of discussion they shall be referred to as the molecular and the colloidal interpretations.

Molecular Interpretations. Sponsler (75) developed in 1926 a conception of native cell wall structure which would account for the known properties upon a molecular basis. He expressed the belief that X-ray diffraction data obtained from plant fibers could be explained by the presence of chains of cellulose unit cells, of indefinite length, thus eliminating the necessity for consideration of the crystalline cellulose micellae (molecular aggregates) of Nägeli (52). Staudinger (76) in 1934, upon the basis of viscosity measurements, likewise postulated the existence of very long molecular chains of cellulose which he believed to be of sufficient size to warrant the name "macromolecule". Others (35) in 1928 had questioned the indefinite length of the cellulose chains, had expressed the opinion that they are comparatively short and that they are arranged in the form of a bundle or a micellar unit. Carothers (13) in 1931 suggested a new type of organization of cellulose chain molecules in the walls of plant fibers in which the long axis of the chains is approximately parallel to the long axis of the fiber, with pronounced overlapping of the ends of the chains.

Thiessen (81) described the new concept in 1938 as follows:

> "The cellulose micelle is an ultramicroscopic mixed crystal of cellulose chains, differing in length. Ends of chains project beyond the micelle ends formed by shorter chains (fringed micelle). Because of the shorter filaments interposed in the micelle core, the fringes have such large lateral distances that van der Waal's forces no longer hold them together. For this reason they tend to separate".

This evolution of the molecular conception of cell wall structure is illustrated in Figure 1. Adaptation of the hypothesis to the interpretation of the behavior of both native and synthetic materials was described in 1938 (31):

> "A revision of the Nägeli hypothesis of discontinuous cellulose micellae was found to be necessary. Evidence was found of a system of connected cellulose threads or layers. Cellulose, in the form of long, chain-like molecules formed a skeletel framework. The molecular weight and length of the chains are not known. They give a crystalline X-ray pattern but never are seen in crystalline form. They are insoluble in all ordinary chemical solvents, but in reagents which will throw them into a viscous matrix their viscosities show that a fairly close relation

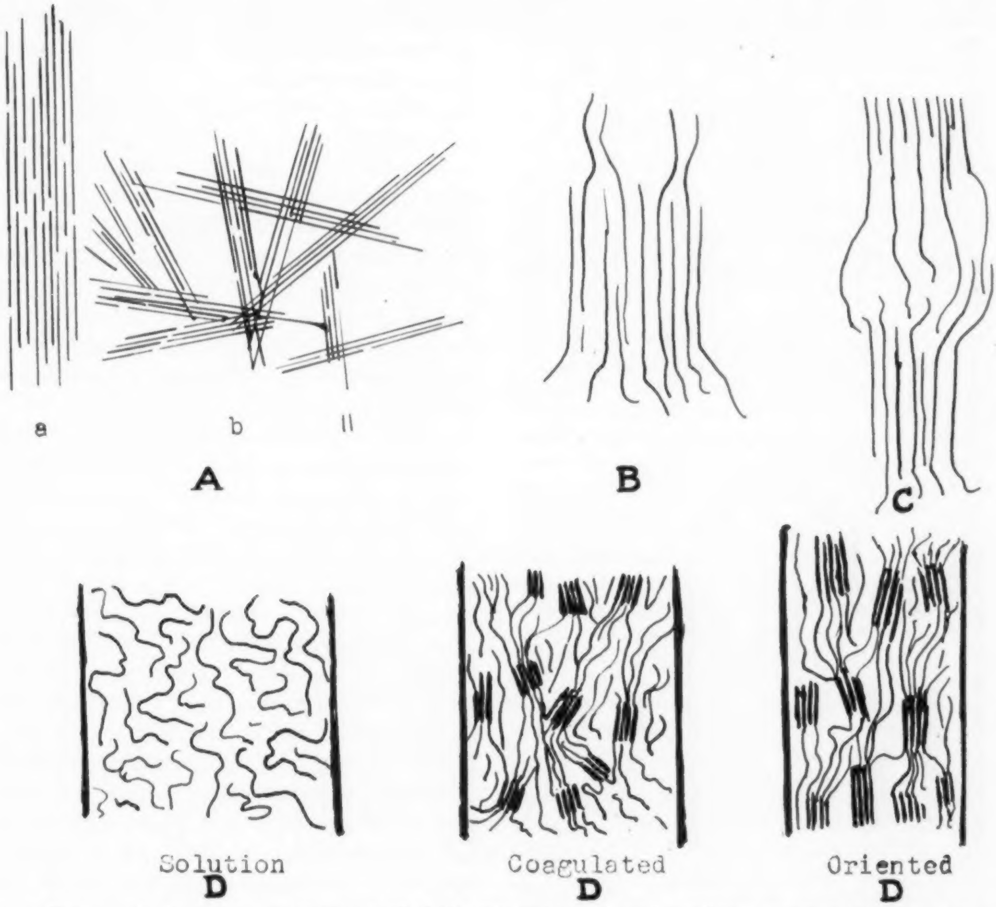

FIG. 1. A. Parallel arrangement of chain molecules (a) and random arrangement of molecular aggregates (b) (*after Carothers*). B. Fringed micelles according to the new theory (*after Kratky*). C. Joining of two micelles by intertwining of fringes through Van der Waal's forces (after *Kratky*). D. Behavior of cellulose chains in a rayon-spinning solution, coagulated and oriented (*after Mark*).

exists between the strength of the whole fiber and the length of the cellulose chain molecules; maximum strength is believed to be reached in chains of about 2,000 glucose residues''.

One of the most recent reviews of this field of research was published in 1943 in the form of a monograph prepared by a staff of specialists under the editorship of Emil Ott (53). The size of the monograph indicates the rapid development of the molecular concept of cell wall structure in the past 20 years. The viewpoint of the treatise is affirmed in the introduction as follows:

``It is the opinion of the editor that the picture of cellulose[1] as a system of long chains of anhydroglucose units is the most important concept in the book. From it may be derived, by the application of ordinary chemical principles, an explanation for almost all the physical and

[1] ``Cellulose'' and ``Chemical cotton'' are used synonomously in the molecular interpretation of cell wall and synthetic fiber properties. Chemical cotton is prepared for industrial purposes from raw cotton linters by first partially removing fragments of stems, seed coats, leaves, *etc.*, by mechanical means, cooking in mild alkaline solutions, bleaching with chlorine, peroxides or other reagents, washing thoroughly and drying. The final product is fibrous and very much whiter than the original unpurified linters.

chemical properties of the molecule. . . . Cellulose tests have been assigned a relatively minor portion of the book because it is felt that this subject is in a quite unsatisfactory state. Most of the tests in common use originated in the days before cellulose chemistry was well understood and have only empirical significance''.

The position now claimed for the molecular interpretation of cell wall structure is evidenced by the following (53):

''On looking backward through the decades from the vantage point of the present, it is easy to see that the chemistry of cellulose remained at a virtual standstill from 1860 to 1920 because ancillary sciences indispensible to the solution of the problem, were in an undeveloped condition. By 1920 the labors of Emil Fischer and other investigations had placed the chemistry of the simple sugars upon a solid foundation. The methylation method of determining the position of hydroxyl groups in the carbon skeleton completed its long apprenticeship, in the hands of Purdie, Irvine, Denham, Woodhouse, and others, about the same time, and the essential, partly methylated glucoses had been prepared and characterized. X-rays gave the first clear diffraction pattern of fibrous cellulose in 1920 and shortly thereafter the colloid chemistry[2] of linear micro-molecules, such as cellulose proved to be, was very greatly clarified by Staudinger and his collaborators. These events make it convenient to choose the year 1919 when Emil Fischer died, as the beginning of the modern period of cellulose chemistry''.

These brief comments and quotations serve to indicate the comprehensive efforts which are being made to interpret the physical properties of cell walls and synthetic materials manufactured from cell walls, upon the basis of the molecular properties of cellulose. As experimental work in this field continues, evidence of more and less highly reactive regions in the wall material has led to a distinction between ''crystalline cellulose'' and ''amorphous cellulose'' (11). In the purification treatments for industrial processing, non-cellulosic materials are considered to have been removed completely, and the factors concerned in the nitration acetylation, xanthation, *etc.*, to be those relating to the effects of processing upon the crystalline and amorphous states of the cellulose alone.

In the course of the development of the molecular interpretation of the structure and physcal properties of cell walls and synthetic textiles, viscosity and X-ray diffraction measurements were originally used as the experimental basis for theoretical considerations (3, 35). The determination of osmotic pressures was brought into extensive usage later for a similar purpose. Calculated values for molecular weights are obtained by means of both techniques. The work in the field of osmotic pressure determinations has been reviewed comprehensively (87). More recently a ''Light-Scattering'' technique has been used extensively. A review of the theory of light scattering has been given (22, 90), and its application to cellulose acetate has also been reported (77).

Colloidal Interpretations. Progress in the field of the colloidal interpretation of cell wall structure and composition has been more or less continuous for more than a century. Lyngbye (45) observed ''minutissime punctata'' in the cell wall of a marine alga in 1819. Valentin (85) and many of his contemporaries found that cell walls increase in thickness by the deposition of material from the protoplasm upon their inner surfaces. In some cells they found microscopically visible granules joined together end to end to form fibrils which, in turn, were deposited as wall material. Others (1, 50) found that the fibrils of the cell wall are separable entities, and that the spiral fibrils do not pass from

[2] The chemistry of ''high-polymers'' or linear ''macromolecules'' is classified by Purves as a branch of colloid chemistry, and a ''colloidal interpretation'' in the sense used here is referred to by Purves as the ''Association Theory''. Experimental developments have thus served to make the borderline less sharp between the ''molecular interpretation'' and the ''colloidal interpretation'', and terms commonly applied to colloidal phenomena are found in discussions of both.

one lamella to another. Schacht (62) showed that fibrils, when arranged in opposite directions in the membrane, have opposite properties in polarized light. The granules and fibrils, with their adhering protoplasmic materials, constitute a typical colloid system. These earlier workers were concerned with the physical rather than the chemical aspects of the system. Between 1840 and 1860 others (*e.g.,* 30, 56) made many contributions to the chemical nature of cell wall materials. They identified "cellulose" and "incrusting substances", which interfered with the chemical reactions of the cellulose, and found that cellulose, nitrogenous materials, minerals and pectic substances can be identified in most cell walls. Nägeli (52), using polarized light for microscopic observations, discounted, in the optical sense, the non-doubly refractive, gelatinous wall material of Fremy and Payen, and concluded that the cell wall is made up of microscopically invisible crystalline "micellae" which are nearly contiguous; that by moistening with water or aqueous fluids the surfaces of these micellae take up water and the previously hard substance becomes soft; and that, upon evaporation, the condition is reversed.

The "Micellar Hypothesis" was popular and the conclusions of Payen and Fremy were frequently overlooked until Mangin (47) published his valuable histological memoires dealing with the heterogeneous chemical nature of cell walls in 1889. Strasburger (79) had found, however, that cell walls, in general, have both solid and gel-like constituents, the latter in the form of a reticular colloidal framework; and that growth in thickness takes place by the deposition of gel and granular "microsomes". Molisch (51) found that the microsomes are connected by fine fibrils of protoplasm, while others (34, 82), in effecting the macrochemical separation of cell membrane constituents, found that the removal of masses of this colloidal gel brings about cell wall disintegration.

Farr and Eckerson (26) in 1934, by means of microchemical analyses and observations in polarized light, determined the cellulose nature of Strasburger's gel-coated microsomes and the non-cellulosic nature of the gel itself. The microsomes were renamed "cellulose particles" and the gel "cementing material" (Figure 2). Others (*e.g.,* 36, 88) have described a similar two-phase structure in cell walls. Wieler compares the relation of the cellulosic and non-cellulosic membrane materials with that of the droplets of honey in the honey-comb to the comb itself. Hess and co-workers (37) have reported that fiber walls are made up mostly of crystalline cellulose surrounded by a thin sheath of other materials which they have named "Hautsubstanz". They have concluded that the recognition of these two fiber components is important for the understanding of fiber structure as well as for reactions to reagents. In both ramie and cotton fibers they have found that the nitrogenous "foreign substance" is frequently held fast during the purification process. Farr and Eckerson (27) have reported that the purified state of cellulose is not approached until the fibrous state is destroyed and the residue is in the form of a fine white powder. This change in physical state they have described as "fiber disintegration," brought about by removal of non-cellulosic cementing material, and not as "cellulose degradation" which would involve changes in the crystalline cellulose itself. These findings have developed into the conception that the fiber wall is made up mostly of particulate crystalline cellulose which diffracts X-rays and is doubly refractive in polarized light, surrounded by a thin sheath of non-cellulosic material which is non-doubly refractive and amorphous. They are not

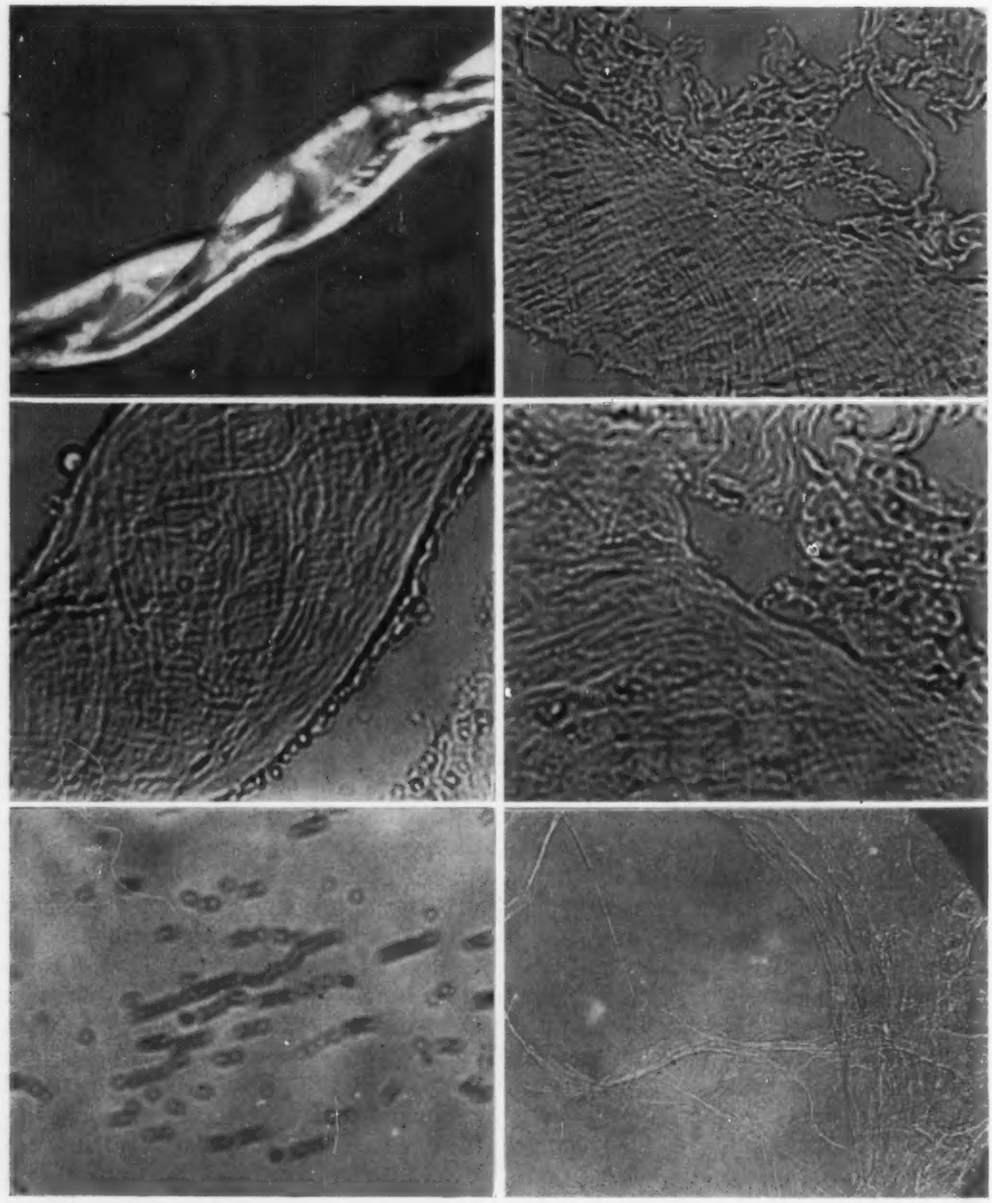

FIG. 2. A (*Upper left*). Single cotton fiber with typical convolutions. B (*Upper right*). Fiber disintegration, showing individual fibrils and cementing material or "Hautsubstanz", ×500. C (*Center left*). Disintegrating fiber washed with solvent for cementing material reveals particulate structure of spiral fibrils. ×700. D (*Center right*). Later stage of fiber and fibril disintegration. ×700. E (*Lower left*). Single fibrils composed of rows of cellulose particles show swelling and blue coloration in sulphuric acid and iodine. ×700. F (*Lower right*). Fibrous pectate prepared according to the method of Baier and Wilson. ×1,380.

in keeping with the conception (7) that the cotton fiber wall is a continuous matrix of cellulose, some portions of which are denser than others, and that the lamellate appearance of the wall is due to alternating zones of dense and less dense cellulose (43).

In 1938 Farr (24) described the colloidal reaction of the cotton fiber wall constituents in cuprammonium hydroxide to be primarily that of the non-cellulosic materials in which the cellulose particles become dispersed. This result is corroborated by some workers (9, 44) but is questioned by others (38, 39) who consider the reaction to be one of the cellulose component of the wall and affirm the value of the measurement of the cuprammonium viscosity of fibrous materials as a basis for determining the molecular weight of cellulose.

In 1939 Compton (18) reported a study of the reactions of cotton fiber wall constituents during the xanthation of fibrous materials. The two-phase structure of the wall was in evidence throughout, and the identity of the cellulose particles was not destroyed during viscose formation.

Farr (25) described in 1941 the microscopic aspects of the synthesis of cellulose in cellulose-forming plastids of living cells. During the period of formation the cellulose is surrounded by a colloidal matrix rich in protein and pectic material, and the final cell wall structure is the result of the organization of these and other protoplasmic components into a continuous, chemically heterogeneous, colloidal system.

Current Trends in the Interpretation of Structure and Properties

Hess (37) has recently confirmed his earlier observations of a primary wall of the native fiber whose structure, composition and texture are different from those of the secondary wall; and for the fibrils of the secondary lamellae, a surrounding-membrane of non-cellulosic material—probably pectin. He reports, in addition, a hitherto unobserved structural element which he has named a "ground fibrilla". Its relation to the other structural elements can be seen from the accompanying table.

STRUCTURAL ELEMENTS	DIAMETER	LENGTH	LIGHT SOURCE
Primary wall	$\sim 0.5\ \mu$		
Lamellae	$\sim 0.2\ \mu$		U. V. $\eta = 2750$ A°
Fibrils	$\sim 0.2\ \mu$		U. V. $\eta = 2750$ A°
Fibril segments	$\sim 0.2\ \mu$	$0.25\ \mu$	U. V. $\eta = 2750$ A°
Ground-fibrillae	80–150 A°	$(0.25\ \mu)$	Electronbeam
Crystalline Micellae	$>$ 60 A°	$>$ 1000 A°	Cu Ka Radiation
Molecule	4.5 A°	Unknown	

The "fibril segments" referred to in this table correspond to the "microscomes" of Strasburger, the "cellulose particles" of Farr and Eckerson and the similar structures described by Wieler in the cells of the "honeycomb". The dimensions as given by these authors are $0.5\ \mu$, $1.1 \times 1.5\ \mu$ and $1.25\ \mu$ respectively. Measurements made in fresh and dried material, unswollen and slightly swollen states, and in different optical systems, may account for these differences. The measurements of fibril segments were made by Hess with an ultraviolet light source. The ground fibrillae, into which the fibril segments separate, were observable only in the electron microscope because of their diminutive size.

The ground fibrillae of Hess do not seem to correspond in their described origin and appearance with the extremely fine fibrillar structures reported in the electron microscopic studies of cell wall materials by others (8, 61, 66). These latter structures have more in com-

mon with the anastamosing fibrils, some of which grade down to and beyond the limits of microscopic visibility, described by Bailey and Kerr.

The chemical nature of these fine anastomosing fibrillae is not decided. The group of authors referred to above, along with Bailey and Kerr, have stated that they are cellulose. Wieler (88) reports similar structures in swelling reactions of many types of cell walls and has found that they represent one of the colloidal states of the continuous phase of the cell wall (honey-comb) in which the cellulose granules are imbedded. Others (6), in a discussion of "fibrous pectates", may have supplied a possible explanation of this finely fibrillar cell wall substance. Figure 2F illustrates a fibrous pectate and its microscopic structure, as observed in ordinary light. As indicated by Wieler, such microscopic phenomena are not uncommon in the manipulation of cell wall materials. Observation of the subdivision of fibril segments into ground fibrillae would require, on the other hand, extremely careful manipulation of wall materials in all stages of preparation for electron microscopic observation. (36).

Hess reports, in addition, that synthetic fibers, beside the well known X-ray structure, have no macromolecular structure which will compare with the ingenious structure of the natural fiber. He considers it likely, however, that in some cases of industrial processing, the "ground-fibrillae" are merely swollen, not broken down, and are again reconstituted in the process of coagulation. These observations, as well as others (18, 24, 44), indicate the necessity for further study of the microscopic structure of synthetic fibers produced from cell walls, at all stages of industrial processing.

Still other workers (23) have contributed a detailed microscopic study of swelling reactions of native fibers in acids and alkalis. From all types of swelling and splitting observed, in which widespread disintegration of the swollen fiber takes place, small uniform-sized ($0.5 \times 1.5\ \mu$) particles were obtained in the form of unswollen residues. In less completely disintegrated fibers these particles are seen with their long axes parallel to the fibril axis, and the authors state that they are probably identical with the "cellulose particles" described by Farr. Continued treatment with hydrolysing agents brings about disappearance of the particles themselves.

The nature and importance of the non-cellulosic constituents of both native cell walls and processed materials has been reflected in a number of recent studies:

Wurz and Swoboda (89), applying quantitative methods for uronic acids to easily parchmentizable and bleached sulfite pulps, found (calcd.) galacturonic acid values of 2.05%–2.5%. Pulps that showed poor parchmentizability contained 1.4%–1.6%, and very poor pulps 0.77%–0.94% galacturonic acid. The authors discount the possibility of the influence of oxycellulose in the pulp. Addition of calcium pectate to a pulp not readily parchmentizable improved its properties.

The non-cellulosic incrustants in the jute fiber resemble, in their behavior, starch-size on a low-twisted, sized, cotton yarn, and while they themselves have little tensile strength, they contribute, in a marked manner, to the strength of the jute by cementing together the ultimate cellulose fiber bundles upon which the strength fundamentally depends (59).

The "hemicelluloses", named first (63) to denote a group of substances in the cell wall considered very closely related to cellulose and as intermediate substances in its development, are being studied intensively. Vincent (86) reports that while most hemicelluloses are soluble in alkali, no alkali extraction ever removes all the hemicellulose from fibrous material; that hemicelluloses are

not homogeneous, some fractions containing uronic acid, and that it is not satisfactory to classify these non-cellulosic materials as "hemicelluloses" and "polyuronides"; that hemicellulose in pulp gives added strength and less resistance to beating; that high hemicellulose content is not indicative of low viscosity; and that it is demonstrated beyond all reasonable doubt that high hemicellulosic content is very desirable in wood pulps. Some (2) have isolated and analyzed "hemicellulose" fractions from aspen holocellulose. The results indicate the presence of galacturonic acid residues, which makes it highly probably that the fraction contains pectic material. Others (48) have found that hemicelluloses from liquefied tissues consist of uronic acid (generally *d*-glucuronic) united to a series of *d*-xylose units with which *d*-glucose may be associated. They resemble gums and mucilages in that on hydrolysis they yield sugar units and a more resistant portion, an "aldobionic acid", which contains the uronic acid.

pH motility curves for "depectinized" cotton continue to shift as treatment with 1% NaOH continues, and from the shape of the curve they never reach a base line (72). The curve does not change in shape after 16 hours. This indicates that some pectic material is retained, although previous work indicated that all was removed after this length of treatment.

The electrochemical activity of collodion membranes depends entirely upon the presence of impurities of an acidic (anionic) nature contained in the collodion used for their preparation (71). Active acidic impurities are largely due to partial oxidation which occurs in the manufacturing process, and partially due to acidic groups which are present in the native cellulose.

In the field of current research in the molecular interpretation of structure and properties, Seymour reports (68):

"Fibers are all high molecular weight products and are related structurally to plastics and rubber. According to Mark the criterion which determines whether a macromolecule is a rubber, a plastic, or a fiber is based upon its ability to crystallize. If the chain-like molecules fit well into the lattice they will crystallize and be fiber-like. If the forces between the chains are greater than 5,000 calories per unit mol, the product will exhibit the properties of a fiber. If the forces are less than 2,000 calories per mol, the product will be rubbery, and products having values in between will be plastics".

Gordon (33) points out the tendency to study fundamentally the polymerization of single pure monomers, and, in the words of Mark and Raff, "although copolymerization is playing an increasingly important rôle in the preparation and technical production of high polymers, only very little is known about the mechanism of this process."

"Recent Progress in Cellulose Chemistry" (5) states that the most promising advance in studies of the degree of polymerization of molecules is in the use of carefully fractionated samples. Calculations by several different methods all lead to similar values which indicate that the molecules are neither fully stretched nor randomly linked or coiled, but assume an intermediate shape of moderate undulation which becomes increasingly kinked as the degree of polymerization increases. They add that it is important to determine the ratio of amorphous to crystalline or ordered regions in cellulose, since the amorphous regions are more easily accessible to chemical attack, *e.g.*, water uptake, absorption of organic vapors and of dyes.

Fibers from Seaweeds

One of the most significant current events in the field of research dealing with cell walls and synthetic textiles is the successful manufacture of "alginate" fibers. Under the title of "Seaweed Rayon" Speakman (74) reviewed the progress in this field in 1945. Tseng (83) in the same year helped to clarify the confused viewpoints of these new

products in a short article entitled "The Terminology of Seaweed Colloids". In conclusion he remarks:

"In view of our incomplete knowledge of their chemistry it is still too early to propose a critical classification of seaweed colloids. It may be said, however, that there seem to be three groups of phycocolloids. First of all, we have the water-soluble ethereal sulfates as represented by agar, carrageenin, and fucoidin; they are similar to mucilages in some of their properties. Secondly, there are the water-soluble reserve carbohydrates consisting exclusively of glucose units; they are represented by laminarin and occupy a position similar to that of starch in land plants. In the third group we have the alkali soluble polyuronides, represented by algin, which are analogous to pectin".

A tentative systematic arrangement of useful seaweeds and seaweed colloids given in diagrammatic form furnishes information with which both biologists and industrialists may conjure (83). The impressive array of cell wall materials, the ease with which many of them may be separated for identification and determination of physical properties, and their chemical relationships to the wall materials of fibrous cells of higher plants, indicate their value for studies fundamental to the understanding of both native and processed cell wall materials.

Of particular interest is the rôle played by sodium and calcium in the current manufacture of seaweed textiles. Speakman and Chamberlain (73), using principles of current viscose practice, report that rayon of satisfactory appearance, handle and strength may be obtained by extruding a solution of sodium alginate into a coagulating bath of N calcium chloride, 0.02 N hydrochloric acid and 2.5% by volume of olive oil emulsified with an agent such as Lissapol C. In a later paper Chamberlain and coworkers (14) state that calcium alginate yarn seems to be suited as the stock material for all purposes. It can be converted into woven or knitted fabrics which can then be made alkali-resistant in finishing by forming chromium or beryllium alginates.

These reactions of seaweed colloids suggest the value of comparisons with the reactions of the pectic material of higher plants (6) as well as the important functions played by calcium in the membranes of living cells. That such comparisons have given and still are giving pause in theoretical developments is indicated in the following quotation (4):

"The fibrous poly-saccharide from seaweed, alginic acid (poly B-niammuronic acid), gives an excellent X-ray fiber photograph, but contrary to expectation the period along the fiber axis is not the same as that of cellulose (10.3 Å), but 8.7 A°, in spite of the fact that the chain molecules are undoubtedly in a fully extended configuration. The unification here consists in explaining this paradox in terms of *one and the same set of postulates, viz.*, the ordinary accepted inter-atomic distances and bond angles. In both cases the ring is the Sachse "armchair", but at the two ends of this armchair there are two possible directions of the glucosidic oxygen bond: one holds in cellulose and the other in alginic acid. Either configuration may pass to the other by virtue of intramolecular oscillations, from which it follows that 10.3 is not the prerogative of cellulose and the 8.7 period is not the prerogative of alginic acid. It is now conceivable that derivatives of either may be found, under the right conditions, to have either period. Neither are these two periods characteristic of B residues only, for the alginic acid configuration is apparently assumed also by pectin, which is built from d-galacturonic acid residues".

It is to be expected that, from the industrial development of seaweed textiles, valuable information concerning the many types of cell wall constituents there represented, and their relation to the physical properties of both the native and processed states, will be more clearly understood. It is to be hoped that all of the valuable techniques which have been developed in connection with both the molecular and the colloidal interpretations of cell wall composition will be brought to bear upon the problems to the end that the properties of cell wall com-

ponents throughout the plant kingdom may be more accurately appraised.

Conclusion

The biologists, chemists and industrialists of the past century based their interpretations of the nature of cell walls and synthetic textiles upon chemical analyses, microscopic analyses and the general colloidal behavior of the materials exhibited in their native and processed states. The investigations of the present century have added to these the more or less generally used techniques of X-ray diffraction (3), refinements in viscosimetry (76) and osmometry (87), electrophoresis (46), ultra-centrifugation (57), electron microscopy (58), ultraviolet microscopy (37, 69), microradiography (16), microincineration (80), phase difference microscopy (10) and the production of crystalline galacturonates (42). It is encouraging to note that data obtained by means of these techniques are being used in both the molecular and the colloidal interpretations of the properties of cell walls and synthetic textiles. The intensive research now in progress and careful evaluation of the data obtained may lead, within this century, to the solution of many of the problems in structure and composition which are here outlined and briefly discussed.

Summary

1. The manufacture of synthetic textiles was anticipated by Robert Hooke in a treatise on microscopy published in 1665.

2. Researches of John Mercer, Edward Schweizer, and contemporary workers laid the foundations of present industrial practices during the middle of the nineteenth century.

3. In 1885 Count Hilaire de Chardonnet obtained a British patent covering the first successful commercial process for the preparation of artificial silk.

4. Man-made fibers are currently manufactured from plant cell-wall material under such technical names as "cellulose nitrates", "cellulose acetates", "cellulose xanthates" and "cuprammonium mellulose".

5. The trade names "artificial silk", "rayon" and "synthetic fibers" are applied, upon occasion, to any one of these processed forms. The terminology is confused, and efforts are being made to clarify it.

6. Plant fibers are used almost exclusively for the manufacture of synthetic textiles, although seaweeds are now being processed for similar purposes.

7. In the production of man-made fibers the art has preceded the science, and the structure and composition of both native and processed materials are not clearly understood. Accumulated information has led to the development of the "molecular" and the "colloidal interpretation".

8. The molecular interpretation holds that the cellulose molecule is the functional unit which determines the properties of native cell walls as well as their synthetic derivatives. The colloidal interpretation explains the same properties upon the basis of a heterogeneous chemical system, established through the vital activity of the colloidal protoplasm, and persisting, in varying degrees, throughout the treatments involved in industrial processing.

9. Examples from various parts of the plant kingdom reveal the fact that the properties of plasticity and deformability are achieved in native cell walls through the use of non-cellulosic materials; that membranes rich in cellulose are no longer plastic; and that extraordinary procedures are involved in reversing this state of rigidity in the mature cell wall. Industry relies upon more or less drastic chemical and physical processes; the cells themselves bring

about such a reversal through the use of enzymes.

10. It is to be hoped that all of the valuable techniques which have been developed in connection with both the molecular and colloidal interpretations will be brought to bear upon the problems of current importance to the end that the properties of cell walls and synthetic textiles may be more accurately appraised.

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Utilization Abstracts

The Shelterbelt Project Pronounced a Success. In 1934 the most ambitious utilization of living trees and shrubs ever conceived to diminish the injurious effects of adverse climatic conditions, was instituted in the United States as the Prairie States Forestry Project and thereafter popularly known as the Shelterbelt Project. "Its chief purposes were, through tree planting, to ameliorate drought conditions, protect crops and livestock, reduce dust storms, and provide useful employment for a drought-stricken people" in a strip of the country extending from Canada through North and South Dakota, Nebraska, Kansas and Oklahoma into central Texas.

The idea originated with President Franklin D. Roosevelt in 1932 and its execution was stimulated by the drought and dust storms of 1934. It was planned and carried out by the U. S. Forest Service and Soil Conservation Service, almost exclusively on relief funds, beginning in 1935 and continuing until 1943 when the Works Progress Administration was terminated. On the basis of extensive preliminary studies, the project was pursued from 1935 through 1942 by planting 220 million trees and shrubs in 30,223 belts on 33,000 farms, the belts covering 238,000 acres and totaling 18,600 miles in length. Most of the belts were along property lines and varied in length from one-eighth to one, and in a few instances to two, miles. Within the belts the number of rows of trees and shrubs varied from one to 56. The rows within the belts were from eight to 14 feet apart, and the trees were from six to eight feet apart, the shrubs from two to four feet apart.

In 1944 a survey was made in order to appraise the results of the project. Of the more than 30,000 belts originally planted, 1,079 were examined, or 3.6%, which represented 2.7% of the total mileage and about 3% of the 220,000,000 trees and shrubs. Many features were taken into consideration in this survey and a detailed report rendered on the survival of the 44 kinds of trees and shrubs planted. These notes constitute a résumé of that report, excerpts from the summary of which are:

"In terms of meeting the main purpose for which the belts were established, that of protection against wind, the Project was a success. For the area as a whole, 78.4 percent of the belts were rated as good or better, and only 10.4 percent as unsatisfactory. Tree survival throughout the entire area covered was generally good. Survival of those species which were planted in more than 100 rows (probably also in more than 100 belts) ranged from 39.2 percent for ponderosa pine (267 rows), the poorest, to 85.0 percent for boxelder (159 rows), the best.

"Benefits which have already been derived from the program include landscape improvement, control of wind erosion, snow traps along highways, protection of farmsteads, gardens, orchards, and feed lots, providing a haven for game and song birds, furnishing wild fruit for preserves, providing fence posts and small poles for use on the farm, and bringing new districts into the soil conservation program.

"The Shelterbelt Project has been a success." (*E. N. Munns and J. H. Stoeckeler, Journal of Forestry 44: 237. 1946*).

Chemical Utilization of Wood. The very important problem of profitable utilization of the huge amount of wood annually wasted in the United States is one of the chief concerns of the Forest Products Laboratory, operated by the U. S. Forest Service at Madison, Wisconsin. While the Laboratory's approach to the problem is from the chemical standpoint, it is recognized that "economical harvesting and transporting of wood waste so that it can be delivered cheaply for chemical use seems to be the biggest obstacle confronting the chemical utilization of wood".

Such chemical utilization of wood waste may be divided into six categories, *viz.*, pulping, extraction, hydrolysis, destructive distillation, reactions with various chemicals, and chemical treatment to improve the qualities of wood.

Pulping yields not only paper pulp on a large scale but also tannin from chestnut chips on a smaller scale. Waste liquors from pulping processes are sources of soluble lignin, hemicelluloses and wood extractives, all of considerable potential value. Turpentine and tall oil are now being recovered to a limited extent from the sulphate pulping of southern yellow pine. Tall oil is used in drying-oils and soaps. Sulphite waste liquor finds some use as a dust settler for roads. Lignin is serving as a dispersing agent for cement in the making of concrete, and is being incorporated in the negative-plate paste of electrical storage batteries; it also finds use in the manufacture of vanillin, the active constituent in vanilla extract. Soda-mill lignin may become useful for laminated plastics without addition of auxiliary resin, and it has been shown to be useful as a phenolic-resin diluent. The hemicelluloses are converted almost entirely to sugars in the sulphite process, and those sugars, to some extent, are being fermented to ethyl alcohol and used for growing yeast.

Extraction processes still await much development and can be profitably applied at present to only a few species, yielding, in particular, turpentine and rosin from southern pine stumps, and tannin from chestnut and hemlock.

Hydrolysis of the carbohydrate portion of wood to sugar, and then fermentation of the latter to alcohol, represent the generalized process of manufacturing ethyl or grain alcohol from wood waste. "If all the sulphite liquor from pulp mills producing more than 100 tons of pulp a day were fermented, alcohol production from this source would be about 30 million gallons of alcohol per year, which is about 3 percent of the present annual production." Such manufacture must compete with alcohol production from grain and possible production from petroleum.

Fermentation of wood sugars can also produce acetone, butanol, 2,3-butylene glycol and lactic acid, useful as solvents and as raw materials in making synthetic rubber and plastics. And fodder yeast can be grown on the total sugars as well as on the still bottoms.

Destructive distillation of wood, formerly an industry of some size, has dwindled since development of the present method for making synthetic wood alcohol, and revival of the industry is dependent upon the development of new techniques.

Studies in the hydrogenation of wood have shown that lignin dissolved in organic solvents or suspended in water can be made to react with hydrogen gas, producing new cyclic alcohols that show promise as plastic solvents, antiknock agents for motor fuel, and toxic agents.

Lastly, there is the production of modified woods through treatment with resins and in other ways. (*A. J. Stamm, Journal of Forestry 44: 258. 1946*).

Sunflower Seeds. Sunflower seeds contain 32%–45% of edible oil, and the plants have long been extensively grown in the U.S.S.R., Roumania and Argentina for production of oil. More recently the crop has made headway in the U.S.A., Canada, Uruguay, Hungary, Rhodesia and other lands. In 1940, under the impetus provided by the war through a decreased supply of vegetable oils, experiments were undertaken in Great Britain toward raising the plants as a source of oil. The results so far indicate that they can be commercially grown and utilized there. A book of 155 pages and 20 plates has recently been published in London on the subject: Hurt, E. F.—Sunflower for food, fodder and fertility.

Sunflower oil is a semi-drying oil equal to the best olive oil in its medicinal and feeding

value for human consumption. It is excellent for margarine and salad oil and as a substitute for cooking lard. The seeds make good poultry feed and the residue from oil extraction is a valuable livestock feed. (*W. B. Brierley, Nature 157: 604. 1946*).

Medicinal Plants. In northeastern United States—New Jersey, New York and all the New England states—there are 67 wild species of herbaceous plants (listed in the article) possessing medicinal properties that might serve as commercial sources of drugs, but which have not yet been used as such, not even in the recent war emergency. So far as Maine is concerned, for instance, only a little collecting of juniper berries and of lycopodium spores has been profitably conducted by a few individuals.

Cultivation of drug plants in the area, except for temporary spurts, has decreased since World War I. In 1918, for example, four growers in New Jersey raised belladonna on about 35 acres; in 1941 the acreage was practically nil. In some other states, however, including Wisconsin, Pennsylvania, Virginia, Tennessee and Ohio, belladonna was harvested on 400 to 500 acres in the autumn of 1942 as a result of seed distribution by the U. S. Department of Agriculture in the spring of that year.

At least nine other kinds of drug plants (listed in the article) were found in approximately 2,400 nurseries, but of them only *Convallaria* was being raised in considerable quantities. (*R. H. Cheney, Bull. Torrey Bot. Club 73: 60. 1946*).

Pre-harvest Fruit Drop. In 1939 it was announced that premature fruit drop can be prevented in fruit trees by use of hormone sprays, and by 1942 commercial use of such sprays had developed to the extent that 75,000 to 80,000 acres of apples were treated that year in the United States. More recently experiments have been conducted during five seasons on the use of such sprays on five varieties of apple and one of pear at the East Malling Research Station, England. α-naphthaleneacetic acid in concentrations ranging from 2¼ to 10 p.p.m. were tried. A large significant gain in crop was obtained with the pear and three of the apple varieties. (*M. C. Vyvyan, Jour. Pom. & Hort. Sci. 22: 11. 1946*).

Peanuts. At the Southern Regional Research Laboratory, New Orleans, a comprehensive investigation is under way concerning the industrial utilization of peanuts. An excellent account of this work was published last year, and these notes are based on that report.

The increased demand for new sources of oil that resulted from the recent war was in part responsible for stimulating the American peanut industry to such a degree that during the war it experienced a five-fold increase in cash value, finally bringing an estimated $200,000,000 annually to Southern farmers who produce the crops, and making peanuts in 1945, for the first time, the number one cash crop in Georgia.

Industrial utilization of peanuts, always secondary in importance to their use as food, involves, primarily, crushing them for oil and use of the residual high-protein meal as livestock feed. For these purposes peanuts are normally used that do not meet food quality standards or that are in excess of food requirements.

In 1940–41 35% of the peanut crop was crushed, producing 171,000,000 pounds of oil and 260,000,000 pounds of meal. Of this production 75% to 90% of the oil was consumed in the manufacture of shortening and oleomargarine; all the meal went into livestock feed.

The industrial problems awaiting solution are concerned in part with finding uses for the by-products of the food- and oil-producing processes, namely, the hulls, skins and embryos, and with obtaining greater extraction of oil—from 5% to 9% of it remains in the meal with present customary methods of hydraulic pressure. About 30,000 tons of hulls and 12 to 15 million pounds each of skins and embryos accumulate annually in the United States as by-products of the major industrial processes. The manufacture of peanut butter is the principal source of skins and embryos. Solvent extraction of the oil is not commercially employed in this country, though that method leaves as little as 1% of oil in the meal.

About 90% of the peanut oil produced in this country goes into edible products, principally vegetable shortening and oleomargarine. Some goes into salad and cooking oils. Other uses of the oil include the manufacture of soap and shaving cream,

face creams and other cosmetics, and pharmaceutical preparations. And still other uses, minor in importance and still more or less in experimental stages, are as a massage oil in the aftertreatment of infantile paralysis; as a carrier of drugs, such as adrenalin and penicillin; in boring compounds, oil sprays and insecticide emulsions; as a textile or other lubricant; for leather impregnation; as a Diesel fuel; and as a gasoline and kerosene substitute. The oil is not suitable, however, in the manufacture of mayonnaise and salad dressings, for it may not remain completely fluid at refrigerator temperatures.

The Southern Research Laboratory is concerned with the development of all these and other possibilities, as well as with the preparation of peanut proteins which may become the basis of textile fibers, adhesives, coatings, sizes and plastics, and a possible source of amino acids. In England peanut protein fiber has been marketed under the name Ardil. (*C. L. Wrenshall, Chemurgic Digest 5(9): 157. 1946*).

Shelterbelts in Russia. In the subtropical districts of Georgia, U.S.S.R., there are miles of tree shelterbelts planted to protect tea and citrus plantations against wind. Some of them are 10 to 12 years old with trees up to 35 feet in height. The best trees for this purpose have been found to be *Sequoia*, *Cryptomeria*, cypress, tulip, plane and poplar, the most profitable of all, in view of its also furnishing much cordwood, being *Cryptomeria*. In addition to providing shelter the various species also furnish wood and serve as sources of essential oils and resins. (*N. Yushkevich, Journal of Forestry 44: 206. 1946*).

Castor Beans. In 1850 there were 23 castor oil mills in the United States—in Illinois, Missouri, Virginia, Tennessee, Pennsylvania, Alabama and Arkansas. St. Louis was the commercial center of the industry. In 1870 there were only six mills in operation, in Texas, Missouri, New Jersey and Tennessee. In 1880 the domestic production of castor oil amounted to nearly 24 million pounds, and an additional 2½ million pounds were imported. Thereafter domestic production dropped, reaching about 20,000 pounds in 1920, and today there is not any commercial castor bean production in this country. By 1940, however, importations of the beans had increased to 307¾ million pounds, and the mills handling these importations today are on the East coast.

India formerly was the great source of castor beans, but production has shifted to the New World, and during the recent war importations into the United States were almost entirely from Brazil and Mexico.

From the leaves of castor plants the Woburn Chemical Corporation has developed an insecticide, Spra-Kast, and the stems are a source of pulp and cellulose which can be used in making cardboard containers, wallboard, newsprint and kraft and other papers, provided the economics of handling make it profitable. Oil is extracted from the seeds or beans, and the remaining pomace, which contains a poisonous substance that makes it unsuitable as livestock feed, is used as a high-nitrogen fertilizer.

It is the oil, pressed from the seeds, that is the important and commercially valuable product of the plant. It enters into the manufacture of at least 25 kinds of products (listed in the article), and the foremost new development in its utilization is the production of hydrated castor oil, used as a fast drying oil for paints and varnishes. This hydrated oil accounted for 64 million of the 77 million pounds of castor oil used in 1944. Other quantities are converted into sebasic acid and capryl alcohol for the plastics industries.

Establishment of an American castor bean industry and independence of foreign sources involves solution of various harvesting and handling problems, and to this end the services of plant breeders as well as engineers is needed. Breeding work can contribute by providing strains of suitable height with fine stems and capsules that do not drop or shatter too readily; in short, varieties that will be high-yielding, non-shattering, disease-resistant and adapted to mechanized handling. Work along these lines was conducted by the U. S. Department of Agriculture in 22 States in southern parts of the country in 1941, 1942 and 1943, and similar work is being continued at the Bureau of Plant Industry Station, Beltsville, Md., at the University of Nebraska, Louisiana State University and the Illinois Agricultural Experiment Station. (*R. O. Weibel and W. L. Burlison, Chemurgic Digest 5(9): 167. 1946*).